The SI Metric System of Units and SPE METRIC STANDARD

Society of Petroleum Engineers

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and
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Preface

The SPE Board in June 1982 endorsed revisions to "SPE Tentative Metric Standard" (Dec. 1977 *JPT*, Pages 1575–1611) and adopted it for implementation as this "SPE Metric Standard."

The following standard is the final product of 12 years' work by the Symbols and Metrication Committee. Members of the current Metrication Subcommittee include John M. Campbell, chairman, John M. Campbell & Co.; Robert A. Campbell, Magnum Engineering Inc.; Robert E. Carlile, Texas Tech U.; J. Donald Clark, petroleum consultant; Hank Groeneveld, Mobil Oil Canada; Terry Pollard, retired, *ex-officio* member; and Howard B. Bradley, professional/technical training consultant.

With very few exceptions, the units shown are those proposed and/or adopted by other groups involved in the metrication exercise, including those agencies charged with the responsibility (nationally and internationally) for establishing metric standards. These few exceptions, still to be decided, are summarized in the introduction to Part 2 of this report.

These standards include most of the units used commonly by SPE members. The subcommittee is aware that some will find the list incomplete for their area of specialty. Additions will continue to be made but too long a list can become cumbersome. The subcommittee believes that these standards provide a basis for metric practice beyond the units listed. So long as one maintains these standards a new unit can be "coined" that should prove acceptable.

Part 1: SI—The International System of Units

Introduction

Worldwide scientific, engineering, industrial, and commercial groups are converting to SI metric units. Many in the U.S. are now active in such conversion, based on work accomplished by national[1] and international[2] authorities. Various U.S. associations, professional societies, and agencies are involved in this process, including, but not limited to, American Society for Testing and Materials (ASTM),[3] American Petroleum Inst. (API),[4,5] American Natl. Standards Inst. (ANSI),[3,6] American Society of Mechanical Engineers (ASME),[7] and American Natl. Metric Council (ANMC).[8] The Canadian Petroleum Assn. (CPA) and other Canadian groups have been especially active in conversion work.[13] The Society of Petroleum Engineers of AIME intends to keep its worldwide membership informed on the conversion to and use of SI metric units.

The term "SI" is an abbreviation for Le Système International d'Unités or The International System of Units.

SI is not identical with any of the former cgs, mks, or mksA systems of metric units but is closely related to them and is an extension of and improvement over them. SI measurement symbols are identical in all languages. As in any other language, rules of spelling, punctuation, and pronunciation are essential to avoid errors in numerical work and to make the system easier to use and understand on a worldwide basis. These rules, together with decimal usage, units coherence, and a series of standard prefixes for multiples and submultiples of most SI units, provide a rational system with minimum difficulty of transition from English units or older systems of metric units. Refs. 1 through 4 of this paper are recommended to the reader wishing official information, development history, or more detail on SI; material from these and other references cited has been used freely in this report.

Appendix A provides definitions for some of the terms used.

SI Units and Unit Symbols[3]

The short-form designations of units (such as ft for feet, kg for kilograms, m for meters, mol for moles, etc.) have heretofore been called unit "abbreviations" in SPE terminology to avoid confusion with the term "symbols" applied to letter symbols used in mathematical equations. However, international and national standard practice is to call these unit designations "unit symbols"; the latter usage will be followed in this report.

SI Units

SI is based on seven well defined "base units" that quantify seven *base quantities* that *by convention* are regarded as dimensionally independent. It is a matter of choice how many and which quantities are considered base quantities.[9] SI has chosen the seven base quantities and base units listed in Table 1.1 as the basis of the International System. In addition, there are two "supplementary quantities" (Table 1.2).

Tables 1.1 and 1.2 show current practices for designating the dimensions of base and supplementary physical quantities, plus letter symbols for use in mathematical equations.

SI "derived units" are a third class, formed by combining, as needed, base units, supplementary units, and other derived units according to the algebraic relations linking the corresponding quantities. The symbols for derived units that do not have their own individual symbols are obtained by using the mathematical signs for multiplication and division, together with appropriate exponents (e.g., SI velocity, meter per second, m/s or $m \cdot s^{-1}$; SI angular velocity, radian per second, rad/s or $rad \cdot s^{-1}$).

Table 1.3 contains a number of SI derived units, including all the 19 approved units assigned special names and individual unit symbols.

Appendix B provides a more detailed explanation of the SI systems of units, their definitions, and abbreviations.

SI Unit Prefixes[8]

The SI unit prefixes, multiplication factors, and SI prefix symbols are shown in Table 1.4. Some of the prefixes may seem strange at first, but there are enough familiar ones in the list to make it relatively easy for technical personnel to adjust to their use; kilo, mega, deci, centi, milli, and micro are known to most engineers and scientists.

One particular warning is required about the prefixes: in the SI system, k and M (kilo and mega) stand for 1000 and 1 000 000, respectively, whereas M and MM or m and mm have been used previously in the oil industry for designating thousands and millions of gas volumes. Note carefully, however, that there is no parallelism because SI prefixes are raised to the power of the unit employed, while the customary M and MM prefixes were not. Examples: km^3 means cubic kilometers, *not* thousands of cubic meters; cm^2 means square centimeters, *not* one-hundredth of a square meter. The designation for 1000 cubic meters is 10^3 m^3 and for 1 million cubic meters is 10^6 m^3—*not* km^3 and Mm^3, respectively.

Appendix C gives examples of the vital importance of following the precise use of upper-case and lower-case letters for prefixes and for unit symbols.

Application of the Metric System

General

SI is the form of the metric system preferred for all applications. It is important that this modernized version be thoroughly understood and properly applied. This section, together with Appendix material, provides guidance and recommendations concerning style and usage of the SI form of the metric system.

Style and Usage

Take care to use unit symbols properly; the agreements in international and national standards provide uniform rules (summarized in Appendix C). It is essential that these rules be followed closely to provide maximum ease of communication and to avoid costly errors. Handling of unit names varies somewhat among different countries because of language differences, but using the rules in Appendix C should minimize most difficulties of communication.

Usage for Selected Quantities

Mass, Force, and Weight. The principal departure of SI from the gravimetric system of metric engineering units is the use of explicitly distinct units for mass and force. *In SI, kilogram is restricted to the unit of mass. The newton is the only SI unit of force,* defined as 1 $(kg \cdot m)/s^2$, to be used wherever force is designated, including derived units that contain force—e.g., pressure or stress ($N/m^2 = Pa$), energy ($N \cdot m = J$), and power $[(N \cdot m)/s = W]$.

There is confusion over the use of the term *weight* as a quantity to mean either *force* or *mass*. In science and technology, the term *weight of a body* usually means the force that, if applied to the body, would give it an acceleration equal to the local acceleration of free fall (g, when referring to the earth's surface). This acceleration varies in time and space; *weight*, if used to mean force, varies also. The term *force of gravity* (mass times acceleration of gravity) is more accurate than *weight* for this meaning.

In commercial and everyday use, on the other hand, the term *weight* nearly always means *mass*. Thus, when

TABLE 1.1 — SI BASE QUANTITIES AND UNITS*

Base Quantity or "Dimension"	SI Unit	SI Unit Symbol ("Abbreviation"), Use Roman (Upright) Type	SPE Letter Symbol for Mathematical Equations, Use Italic (Sloping) Type
length	meter	m	*L*
mass	kilogram	kg	*m*
time	second	s	*t*
electric current	ampere	A	*I*
thermodynamic temperature	kelvin	K	*T*
amount of substance	mole†	mol	*n*
luminous intensity	candela	cd	

*The seven base units, two supplementary units and other terms are defined in Appendixes A and B, Part 1.
**SPE heretofore has arbitrarily used charge *q*, the product of electric current and time, as a basic dimension. In unit symbols this would be A·s; in SPE mathematical symbols, *I·t*.
†When the mole is used, the elementary entities must be specified; they may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. In petroleum work, the terms "kilogram mole," "pound mole," etc., often are shortened erroneously to "mole."

TABLE 1.2 — SI SUPPLEMENTARY UNITS*

Supplementary Quantity or "Dimension"	SI Unit	SI Unit Symbol ("Abbreviation"), Use Roman (Upright) Type	SPE Letter Symbol for Mathematical Equations, Use Italic (Sloping) Type
plane angle	radian	rad	θ
solid angle	steradian	sr	Ω

*The seven base units, two supplementary units, and other terms are defined in Appendixes A and B, Part 1.
**ISO specifies these two angles as dimensionless with respect to the seven base quantities.

TABLE 1.3 — SOME COMMON SI DERIVED UNITS

Quantity	Unit	SI Unit Symbol ("Abbreviation"), Use Roman Type	Formula, Use Roman Type
absorbed dose	gray	Gy	J/kg
acceleration	meter per second squared	...	m/s^2
activity (of radionuclides)	becquerel	Bq	1/s
angular acceleration	radian per second squared	...	rad/s^2
angular velocity	radian per second	...	rad/s
area	square meter	...	m^2
Celsius temperature	degree Celsius	°C	K
density	kilogram per cubic meter	...	kg/m^3
dose equivalent	sievert	Sv	J/kg
electric capacitance	farad	F	A·s/V (=C/V)
electric charge	coulomb	C	A·s
electrical conductance	siemens	S	A/V
electric field strength	volt per meter	...	V/m
electric inductance	henry	H	V·s/A (=Wb/A)
electric potential	volt	V	W/A
electric resistance	ohm	Ω	V/A
electromotive force	volt	V	W/A
energy	joule	J	N·m
entropy	joule per kelvin	...	J/K
force	newton	N	$kg{\cdot}m/s^2$
frequency	hertz	Hz	1/s
illuminance	lux	lx	lm/m^2
luminance	candela per square meter	...	cd/m^2
luminous flux	lumen	lm	cd·sr
magnetic field strength	ampere per meter	...	A/m
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m^2
potential difference	volt	V	W/A
power	watt	W	J/s
pressure	pascal	Pa	N/m^2
quantity of electricity	coulomb	C	A·s
quantity of heat	joule	J	N·m
radiant flux	watt	W	J/s
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram kelvin	...	J(kg·K)
stress	pascal	Pa	N/m^2
thermal conductivity	watt per meter kelvin	...	W/(m·K)
velocity	meter per second	...	m/s
viscosity, dynamic	pascal second	...	Pa·s
viscosity, kinematic	square meter per second	...	m^2/s
voltage	volt	V	W/A
volume*	cubic meter	...	m^3
wavenumber	1 per meter	...	1/m
work	joule	J	N·m

*In 1964, the General Conference on Weights and Measures adopted liter as a special name for the cubic decimeter but discouraged the use of liter for volume measurement of extreme precision (see Appendix B).

TABLE 1.4 — SI UNIT PREFIXES

Multiplication Factor	SI Prefix	SI Prefix Symbol, Use Roman Type	Pronunciation (U.S.)*	Meaning (U.S.)	Meaning In Other Countries
1 000 000 000 000 000 000 = 10^{18}	exa**	E	ex' a (*a* as in *a* bout)	one quintillion times†	trillion
1 000 000 000 000 000 = 10^{15}	peta**	P	as in *p* etal	one quadrillion times†	thousand billion
1 000 000 000 000 = 10^{12}	tera	T	as in *terra* ce	one trillion times†	billion
1 000 000 000 = 10^{9}	giga	G	jig' a (*a* as in *a* bout)	one billion times†	milliard
1 000 000 = 10^{6}	mega	M	as in *mega* phone	one million times	
1 000 = 10^{3}	kilo	k	as in *kilo* watt	one thousand times	
100 = 10^{2}	hecto‡	h	heck' toe	one hundred times	
10 = 10	deka‡	da	deck' a (*a* as in *a* bout)	ten times	
0.1 = 10^{-1}	deci‡	d	as in *deci* mal	one tenth of	
0.01 = 10^{-2}	centi‡	c	as in *senti* ment	one hundredth of	
0.001 = 10^{-3}	milli	m	as in *mili* tary	one thousandth of	
0.000 001 = 10^{-6}	micro	μ	as in *micro* phone	one millionth of	
0.000 000 001 = 10^{-9}	nano	n	nan' oh (*an* as in *an* t)	one billionth of†	milliardth
0.000 000 000 001 = 10^{-12}	pico	p	peek' oh	one trillionth of†	billionth
0.000 000 000 000 001 = 10^{-15}	femto	f	fem' toe (*fem* as in *fem* inine)	one quadrillionth of†	thousand billionth
0.000 000 000 000 000 001 = 10^{-18}	atto	a	as in an*ato* my	one quintillionth of†	trillionth

*The first syllable of every prefix is accented to assure that the prefix will retain its identity. Therefore, the preferred pronunciation of kilometer places the accent on the first syllable, not the second.

**Approved by the 15th General Conference of Weights and Measures (CGPM), May-June 1975.

†These terms should be avoided in technical writing because the denominations above 1 million are different in most other countries, as indicated in the last column.

‡While hecto, deka, deci, and centi are SI prefixes, their use generally should be avoided except for the SI unit multiples for area, volume, moment, and nontechnical use of centimeter, as for body and clothing measurement.

one speaks of a person's weight, the quantity referred to is mass. Because of the dual use, the term weight should be avoided in technical practice except under circumstances in which its meaning is completely clear. When the term is used, it is important to know whether *mass* or *force* is intended and to use SI units properly as described above by using kilograms for mass and newtons for force.

Gravity is involved in determining mass with a balance or scale. When a standard mass is used to balance the measured mass, the effect of gravity on the two masses is canceled except for the indirect effect of air or fluid buoyancy. In using a spring scale, mass is measured indirectly since the instrument responds to the force of gravity. Such scales may be calibrated in mass units if the variation in acceleration of gravity and buoyancy corrections are not significant in their use.

The use of the same name for units of force and mass causes confusion. When non-Si units are being converted to SI units, distinction should be made between *force* and *mass*—e.g., use lbf to denote force in gravimetric engineering units, and use lbm for mass.

Use of the metric ton, also called *tonne* (1.0 Mg), is common.

Linear Dimensions. Ref. 3 provides discussions of length units applied to linear dimensions and tolerances of materials and equipment, primarily of interest to engineers in that field.

Temperature. The SI temperature unit is the kelvin (not "degree Kelvin"); it is the preferred unit to express thermodynamic temperature. Degrees Celsius (°C) is an SI derived unit used to express temperature and temperature intervals. The Celsius scale (formerly called centigrade) is related directly to the kelvin scale as follows: the temperature interval 1°C=1 K, exactly. Celsius temperature ($T_{°C}$) is related to thermodynamic temperature (T_K) as follows: $T_{°C}=T_K-T_0$ exactly, where $T_0=273.15$ K by definition. Note that the SI unit symbol for the kelvin is K without the degree mark, whereas the older temperature units are known as degrees Fahrenheit, degrees Rankine, and degrees Celsius, with degree marks shown on the unit symbol (°F, °R, °C).

Time. The SI unit for time is the second, and this is preferred, but use of the minute, hour, day, and year is permissible.

Angles. The SI unit for plane angle is the radian. The use of the arc degree and its decimal submultiples is permissible when the radian is not a convenient unit. Use of the minute and second is discouraged except possibly for cartography. Solid angles should be expressed in steradians.

Volume. The SI unit of volume is the cubic meter. This unit, or one of its regularly formed multiples, is preferred for all applications. The special name *liter* has been approved for the cubic decimeter (see Appendix B), but use of the liter is restricted to the measurement of liquids and gases.

Energy. The SI unit of energy, the joule, together with its multiples, is preferred for all applications. The kilowatt-hour is used widely as a measure of electric energy, but this unit should not be introduced into any new areas; eventually it should be replaced by the megajoule.

Torque and Bending Moment. The vector product of force and moment arm is expressed in newton meters (N·m) by SPE as a convention when expressing torque energies.

Pressure and Stress. The SI unit for pressure and stress is the pascal (newton per square meter); with proper SI prefixes it is applicable to all such measurements. Use of the old metric gravitational units—kilogram-force per square centimeter, kilogram-force per square millimeter, torr, etc.—is to be discontinued. Use of the bar is discouraged by the standards organizations.

It has been recommended internationally that pressure units themselves should not be modified to indicate whether the pressure is "absolute" (above zero) or "gauge" (above atmospheric pressure). If the context leaves any doubt as to which is meant, the word "pressure" must be qualified appropriately: "...at a gauge pressure of 13 kPa," or "...at an absolute pressure of 13 kPa," etc.

Units and Names To Be Avoided or Abandoned

Tables 1.1 through 1.3 include all SI units identified by formal names, with their individual unit symbols. Virtually all other *named* metric units formerly in use (as well as nonmetric units) are to be avoided or abandoned. There is a long list of such units (e.g., dyne, stokes, "esu," gauss, gilbert, abampere, statvolt, angstrom, fermi, micron, mho, candle, calorie, atmosphere, mm Hg, and metric horsepower). The reasons for abandoning the non-Si units are discussed in Appendix B. Two of the principal reasons are the relative simplicity and coherence of the SI units.

Rules for Conversion and Rounding[3]

Conversion

Table 1.7, Appendix D, contains general conversion factors that give exact values or seven-digit accuracy for implementing these rules except where the nature of the dimension makes this impractical.

The conversion of quantities should be handled with careful regard to the implied correspondence between the accuracy of the data and the given number of digits. In all conversions, the number of significant digits retained should be such that accuracy is neither sacrificed nor exaggerated.

Proper conversion procedure is to multiply the specified quantity by the conversion factor exactly as given in Table 1.7 and then round to the appropriate number of significant digits. For example, to convert 11.4 ft to meters: 11.4×0.3048=3.474 72, which rounds to 3.47 m.

Accuracy and Rounding

Do *not* round either the conversion factor or the quantity *before* performing the multiplication; this reduces accuracy. Proper conversion procedure includes rounding the *converted* quantity to the proper number of significant digits commensurate with its intended precision. The practical aspects of measuring must be considered when using SI equivalents. If a scale divided into sixteenths of an inch was suitable for making the original measurements, a metric scale having divisions of 1 mm is obviously suitable for measuring in SI units, and the equivalents should not be reported closer than the nearest 1 mm. Similarly, a gauge or caliper graduated in divisions of 0.02 mm is comparable to one graduated in divisions of 0.001 in. Analogous situations exist for mass, force, and other measurements. A technique to determine the proper number of significant digits in rounding converted values is described here for general use.

General Conversion. This approach depends on first establishing the intended precision or accuracy of the quantity as a necessary guide to the number of digits to retain. The precision should relate to the number of digits in the original, but in many cases that is not a reliable indicator. A figure of 1.1875 may be a very accurate decimalization of a noncritical $1\frac{3}{16}$ that should have been expressed as 1.19. On the other hand, the value 2 may mean "about 2" or it may mean a very accurate value of 2, which should then have been written as 2.0000. It is therefore necessary to determine the intended precision of a quantity before converting. *This estimate of intended precision should never be smaller than the accuracy of measurement but usually should be smaller than one tenth the tolerance if one exists.* After estimating the precision of the dimension, the converted dimension should be rounded to a minimum number of significant digits (see section on "Significant Digits") such that a unit of the last place is equal to or smaller than the converted precision.

Examples

1. A stirring rod 6 in. long: In this case, precision is estimated to be about ½ in. (± ¼ in.). Converted, ½ in. is 12.7 mm. The converted 6-in. dimension of 152.4 mm should be rounded to the nearest 10 mm, or 150 mm.

2. 50 000-psi tensile strength: In this case, precision is estimated to be about ±200 psi (±1.4 MPa) based on an accuracy of ±0.25% for the tension tester and other factors. Therefore, the converted dimension, 344.7379 MPa, should be rounded to the nearest whole unit, 345 MPa.

3. Test pressure 200±15 psi: Since one tenth of the tolerance is ±1.5 psi (10.34 kPa), the converted dimension should be rounded to the nearest 10 kPa. Thus, 1378.9514±103.421 35 kPa becomes 1380±100 kPa.

Special Cases. Converted values should be rounded to the minimum number of significant digits that will maintain the required accuracy. In certain cases, deviation from this practice to use convenient or whole numbers may be feasible. In that case, the word "approximate" must be used following the conversion—e.g., $1\frac{7}{8}$ in. =47.625 mm exact, 47.6 mm normal rounding, 47.5 mm (approximate) rounded to preferred or convenient half-millimeter, 48 mm (approximate) rounded to whole number.

A quantity stated as a limit, such as "not more than" or "maximum," must be handled so that the stated limit is not violated. For example, a specimen "at least 4 in. wide" requires a width of at least 101.6 mm, or (rounded) at least 102 mm.

Significant Digit. *Any digit that is necessary to define the specific value or quantity is said to be significant.* For example, a distance measured to the nearest 1 m may have been recorded as 157 m; this number has three significant digits. If the measurement had been made to the nearest 0.1 m, the distance may have been 157.4 m—four significant digits. In each case, the value of the right-hand digit was determined by measuring the value of an additional digit and then rounding to the desired degree of accuracy. In other words, 157.4 was rounded to 157; in the second case, the measurement may have been 157.36, rounded to 157.4.

Importance of Zeros. Zeros may be used either to indicate a specific value, as does any other digit, or to indicate the magnitude of a number. The 1970 U.S. population figure rounded to thousands was 203 185 000. The six left-hand digits of this number are significant; each *measures* a value. The three right-hand digits are zeros that merely indicate the *magnitude* of the number rounded to the nearest thousand. To illustrate further, each of the following estimates and measurements is of different magnitude, but each is specified to have only one significant digit:

1 000
100
10
0.01
0.001
0.000 1.

It is also important to note that, for the first three numbers, the identification of significant digits is possible only through knowledge of the circumstances. For example, the number 1000 may have been rounded from about 965, or it may have been rounded from 999.7, in which case all three zeros are significant.

Data of Varying Precision. Occasionally, data required for an investigation must be drawn from a variety of sources where they have been recorded with varying degrees of refinement. Specific rules must be observed when such data are to be *added, subtracted, multiplied, or divided.*

The rule for addition and subtraction is that the *answer* shall contain no significant digits farther to the right than occurs in the least precise number. Consider the addition of three numbers drawn from three sources, the first of which reported data in millions, the second in thousands, and the third in units:

163 000 000
217 885 000
96 432 768
477 317 768

This total indicates a precision that is not valid. The numbers should *first* be rounded to *one significant digit* farther to the right than that of the least precise number, and the sum taken as follows.

163 000 000
217 900 000
96 400 000
477 300 000

Then, the total is rounded to 477 000 000 as called for by the rule. Note that if the second of the figures to be added had been 217 985 000, the rounding before addition would have produced 218 000 000, in which case the zero following 218 would have been a significant digit.

The rule for multiplication and division is that the *product* or *quotient* shall contain no more significant digits than are contained in the number with the *fewest significant digits* used in the multiplication or division. The difference between this rule and the rule for addition and subtraction should be noted; for addition and subtraction, the rule merely requires rounding digits to the right of the last significant digit in the least precise number. The following illustration highlights this difference.

Multiplication:	$113.2\times1.43=161.876$ rounded to 162.
Division:	$113.2\div1.43=79.16$ rounded to 79.2
Addition:	$113.2+1.43=114.63$ rounded to 114.6
Subtraction:	$113.2-1.43=111.77$ rounded to 111.8.

The above product and quotient are limited to three significant digits since 1.43 contains only three significant digits. In contrast, the rounded answers in the addition and subtraction examples contain four significant digits.

Numbers used in the illustration are all estimates or measurements. *Numbers that are exact counts (and conversion factors that are exact) are treated as though they consist of an infinite number of significant digits.* Stated more simply, when a *count* is used in computation with a measurement, the number of significant digits in the answer is the same as the number of significant digits in the measurement. If a count of 40 is multiplied by a measurement of 10.2, the product is 408. However, if 40 were an estimate accurate only to the nearest 10 and, hence, contained one significant digit, the product would be 400.

Rounding Values[10]

When a figure is to be rounded to fewer digits than the total number available, the procedure should be as follows.

When the First Digit Discarded is	The Last Digit Retained is
less than 5	unchanged
more than 5	increased by 1
5 followed only by zeros*	unchanged if even, increased by 1 if odd

Examples:
4.463 25 if rounded to three places would be 4.463.
8.376 52 if rounded to three places would be 8.377.
4.365 00 if rounded to two places would be 4.36.
4.355 00 if rounded to two places would be 4.36.

Conversion of Linear Dimensions of Interchangeable Parts

Detailed discussions of this subject are provided by ASTM,[3] API,[4] and ASME[7] publications, and are recommended to the interested reader.

Other Units

Temperature. General guidance for converting tolerances from degrees Fahrenheit to kelvins or degrees Celsius is given in Table 1.5. Normally, temperatures expressed in a whole number of degrees Fahrenheit should be converted to the nearest 0.5 K (or 0.5°C). As with other quantities, the number of significant digits to retain will depend on implied accuracy of the original dimension e.g.,*

100 ± 5°F (tolerance); implied accuracy, estimated total 2°F (nearest 1°C) 37.7778 ± 2.7778°C rounds to 38 ± 3°C.
1000 ± 50°F (tolerance); implied accuracy, estimated total 20°F (nearest 10°C) 537.7778 ± 27.7778°C rounds to 540 ± 30°C.

Pressure or Stress. Pressure or stress values may be converted by the same principle used for other quantities. Values with an uncertainty of more than 2% may be converted without rounding by the approximate factor:

1 psi=7 kPa.

For conversion factors see Table 1.7.

Special Length Unit—the Vara. Table 1.8, Appendix E, provides conversion factors and explanatory notes on the problems of converting the several kinds of vara units to meters.

Special Terms and Quantities Involving Mass and Amount of Substance

The International Union of Pure and Applied Chemistry, the International Union of Pure and Applied Physics,

TABLE 1.5 — CONVERSION OF TEMPERATURE TOLERANCE REQUIREMENTS

Tolerance (°F)	Tolerance (K or °C)
±1	±0.5
±2	±1
±5	±3
±10	±5.5
±15	±8.5
±20	±11
±25	±14

*Unless a number of rounded values are to appear in a given problem, most roundings conform to the first two procedures — i.e., rounding upward when the first digit discarded is 5 or higher.

and the International Organization for Standardization provide clarifying usages for some of the terms involving the base quantities "mass" and "amount of substance." Two of these require modifying the terminology appearing previously in SPE's Symbols Standards.

Table 1.6 shows the old and the revised usages.

Mental Guides for Using Metric Units

Table 1.9, Appendix F, is offered as a "memory jogger" or guide to help locate the "metric ballpark" relative to customary units. Table 1.9 is *not* a conversion table. For accurate conversions, refer to Table 1.7 or to Tables 2.2 and 2.3 for petroleum-industry units, and round off the converted values to practical precision as described earlier.

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8. *Metric Editorial Guide,* third edition, American Natl. Metric Council (ANMC), Washington, D.C. (July 1981).
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12. "Information Processing—Representations of SI and Other Units for Use in Systems With Limited Character Sets," Intl. Standard ISO 2955-1974, Intl. Organization for Standardization, ANSI, New York City. (Ref. 5 reproduces the 1973 edition of this standard in its entirety.)
13. "Supplementary Metric Practice Guide for the Canadian Petroleum Industry," fourth edition, P.F. Moore (ed.), Canadian Petroleum Assn. (Oct. 1979).
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16. McElwee, P.G.: *The Texas Vara.* Available from Commissioner, General Land Office, State of Texas, Austin (April 30, 1940).

*See Appendix A and prior paragraph on "General Conversion."
**For cost and address information on ordering, see paper SPE 6212, or contact SPE Headquarters.

APPENDIX A[3]
Terminology

To ensure consistently reliable conversion and rounding practices, a clear understanding of the related nontechnical terms is prerequisite. Accordingly, certain terms used in this standard are defined as follows.

Accuracy (as distinguished from Precision). The degree of conformity of a measured or calculated value to some recognized standard or specified value. This concept involves the systematic error of an operation, which is seldom negligible.

Approximate. A value that is nearly but not exactly correct or accurate.

Coherence. A characteristic of a coherent system of units, as described in Appendix B, such that the product or quotient of any two unit quantities is the unit of the

TABLE 1.6 — SPECIAL TERMS AND QUANTITIES INVOLVING MASS AND AMOUNT OF SUBSTANCE

Old Usage		Standardized Usage	
Term	Dimensions (ISO Symbols, See Table 1.1)	Term	SI Unit Symbol
atomic weight (SPE Symbols Standard)	M	mass of atom	kg
atomic weight (elsewhere)	*	relative atomic mass	*
equivalent	—	mole	mol
mass of molecule	M	molecular mass	kg
molar	—	molar (means, "divided by amount of substance")	1/mol
molarity	—	concentration	mol/m^3
molecular weight (SPE Symbols Standard)	M	molar mass	kg/mol
molecular weight (elsewhere)	*	relative molecular mass	*
normal — obsolete			

*Dimensionless

resulting quantity. The SI base units, supplementary units, and derived units form a coherent set.

Deviation. Variation from a specified dimension or design requirement, usually defining upper and lower limits (see also **Tolerance**).

Digit. One of the 10 Arabic numerals (0 to 9).

Dimension(s). Two meanings: (1) A group of fundamental (physical) quantities, arbitrarily selected, in terms of which all other quantities can be measured or identified.[9] Dimensions identify the physical nature of, or the basic components making up, a physical quantity. They are the bases for the formation of useful dimensionless groups and dimensionless numbers and for the powerful tool of dimensional analysis. The dimensions for the arbitrarily selected base units of the SI are length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity. SI has two supplementary quantities considered dimensionless—plane angle and solid angle. (2) A geometric element in a design, such as length and angle, or the magnitude of such a quantity.

Figure (numerical). An arithmetic value expressed by one or more digits or a fraction.

Nominal Value. A value assigned for the purpose of convenient designation; a value existing in name only.

Precision (as distinguished from Accuracy). The degree of mutual agreement between individual measurements (repeatability and reproducibility).

Quantity. A concept used for qualitative and quantitative descriptions of a physical phenomenon.[9]

Significant Digit. Any digit that is necessary to define a value or quantity (see text discussion).

Tolerance. The total range of variation (usually bilateral) permitted for a size, position, or other required quantity; the upper and lower limits between which a dimension must be held.

U.S. Customary Units. Units based on the foot and the pound, commonly used in the U.S. and defined by the Natl. Bureau of Standards.[11] Some of these units have the same name as similar units in the U.K. (British, English, or U.K. units) but are not necessarily equal to them.

APPENDIX B[3]

SI Units

Advantages of SI Units

SI is a rationalized selection of units from the metric system that individually are not new. They include a unit of force (the newton), which was introduced in place of the kilogram-force to indicate by its name that it is a unit of force and not of mass. SI is a coherent system with seven base units for which names, symbols, and precise definitions have been established. Many derived units are defined in terms of the base units, with symbols assigned to each; in some cases, special names and unit symbols are given—e.g., the newton (N).

One Unit Per Quantity. The great advantage of SI is that there is one, and only one, unit for each physical quantity—the meter for length (L), kilogram (instead of gram) for mass (m), second for time (t), etc. From these elemental units, units for all other mechanical quantities are derived. These derived units are defined by simple equations among the quantities, such as $v=dL/dt$ (velocity), $a=dv/dt$ (acceleration), $F=ma$ (force), $W=FL$ (work or energy), and $P=W/t$ (power). Some of these units have only generic names, such as meter per second for velocity; others have special names and symbols, such as newton (N) for force, joule (J) for work or energy, and watt (W) for power. *The SI units for force, energy, and power are the same regardless of whether the process is mechanical, electrical, chemical, or nuclear.* A force of 1 N applied for a distance of 1 m can produce 1 J of heat, which is identical with what 1 W of electric power can produce in 1 second.

Unique Unit Symbols. Corresponding to the SI advantages of a unique unit for each physical quantity are the advantages resulting from the use of a unique and well defined set of symbols. Such symbols eliminate the confusion that can arise from current practices in different disciplines such as the use of "b" for both the *bar* (a unit of pressure) and *barn* (a unit of area).

Decimal Relation. Another advantage of SI is its retention of the decimal relation between multiples and submultiples of the base units for each physical quantity. Prefixes are established for designating multiple and submultiple units from "exa" (10^{18}) down to "atto" (10^{-18}) for convenience in writing and speaking.

Coherence. Another major advantage of SI is its coherence. This system of units has been chosen in such a way that the equations between numerical values, including the numerical factors, have the same form as the corresponding equations between the quantities: this constitutes a "coherent" system. Equations between units of a coherent unit system contain as numerical factors only the number 1. In a coherent system, the product or quotient of any two unit quantities is the unit of the resulting quantity. For example, in any coherent system, unit area results when unit length is multiplied by unit length ($1\ m \times 1\ m = 1\ m^2$), unit force when unit mass* is multiplied by unit acceleration ($1\ kg \times 1\ m/s^2 = 1\ N$), unit work when unit force is multiplied by unit length ($1\ N \times 1\ m = 1\ J$), and unit power when unit work is divided by unit time ($1\ J \div 1\ second = 1\ W$). Thus, in a coherent system in which the meter is the unit of length, the square meter is the unit of area, but the are** and hectare are not coherent. Much worse disparities occur in systems of "customary units" (both nonmetric and older metric) that require many numerical adjustment factors in equations.

Base Units. Whatever the system of units, whether it be coherent or noncoherent, particular samples of some

*Note that the kilogram (*not* the gram) is the coherent SI unit of mass.
**The are is an old metric unit.

physical quantities must be selected arbitrarily as units of those quantities. The remaining units are defined by appropriate experiments related to the theoretical interrelations of all the quantities. For convenience of analysis, units pertaining to *certain base quantities are by convention regarded as dimensionally independent; these units are called base units* (Table 1.1), all all others (derived units) can be expressed algebraically in terms of the base units. In SI, the unit of mass, the kilogram, is defined as the mass of a prototype kilogram preserved by the International Bureau of Weights and Measures (BIPM) in Paris. All other base units are defined in terms of reproducible phenomena—e.g., the wave lengths and frequencies of specified atomic transitions.

Non-SI Metric Units

Various other units are associated with SI but are not a part thereof. They are related to units of the system by powers of 10 and are employed in specialized branches of physics. An example is the bar, a unit of pressure, approximately equivalent to 1 atm and exactly equal to 100 kPa. The bar is employed extensively by meteorologists. Another such unit is the gal, equal exactly to an acceleration of 0.01 m/s^2. It is used in geodetic work. These, however, are not coherent units—i.e., equations involving both these units and SI units cannot be written without a factor of proportionality even though that factor may be a simple power of 10.

Originally (1795), the liter was intended to be identical to the cubic decimeter. The Third General Conference on Weights and Measures (CGPM) in 1901 defined the liter as the volume occupied by the mass of 1 kilogram of pure water at its maximum density under normal atmospheric pressure. Careful determinations subsequently established the liter so defined as equivalent to 1.000 028 dm^3. In 1964, the CGPM withdrew this definition of the liter and declared that "liter" was a special name for the cubic decimeter. Thus, its use is permitted in SI but is discouraged because it creates two units for the same quantity and its use in precision measurements might conflict with measurements recorded under the old definition.

SI Base Unit Definitions

Authorized translations of the original French definitions of the seven base and two supplementary units of SI follow[3] (parenthetical items added).

"*Meter* (m)—The meter is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels 2 p_{10} and $5d_5$ of the krypton-86 atom." (Adopted by 11th CGPM 1960.)

"*Kilogram* (kg)—The kilogram is the unit of mass (and is the coherent SI unit); it is equal to the mass of the international prototype of the kilogram." (Adopted by First and Third CGPM 1889 and 1901.)

"*Second* (s)—The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.†" (Adopted by 13th CGPM 1967.)

"*Ampere* (A)—The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed one meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length." (Adopted by Ninth CGPM 1948.)

"*Kelvin* (K)—The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water."[3] (Adopted by 13th CGPM 1967.)

"*Mole* (mol)—The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilograms of carbon-12." (Adopted by 14th CGPM 1971.)

"Note—When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles."

"*Candela* (cd)—The candela is the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540 (E+12) hertz (Hz) and that has a radiant intensity in that direction of 1/683 watt per steradian."

"*Radian* (rad)—The radian is the plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius."

"*Steradian* (sr)—The steradian is the solid angle which, having its vertex at the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere."

†This definition supersedes the ephemeris second as the unit of time.

Definitions of SI Derived Units Having Special Names[3]

Physical Quantity	Unit and Definition
Absorbed dose	The *gray* (Gy) is the absorbed dose when the energy per unit mass imparted to matter by ionizing radiation is 1 J/kg.
Activity	The *becquerel* (Bq) is the activity of a radionuclide decaying at the rate of one spontaneous nuclear transition per second.
Celsius temperature	The *degree Celsius* (°C) is equal to the kelvin and is used in place of the kelvin for expressing Celsius temperature (symbol $T_{°C}$) defined by $T_{°C} = T_K - T_0$, where T_K is the thermodynamic temperature and $T_0 = 273.15$ K by definition.
Dose equivalent	The *sievert* is the dose equivalent when the absorbed dose of ionizing radiation multiplied by the dimensionless factors Q (quality factor) and N (product of any other multiplying factors) stipulated by the Intl. Commission on Radiological Protection is 1 J/kg.
Electric capacitance	The *farad* (F) is the capacitance of a capacitor between the plates of which there appears a difference of potential of 1 V when it is charged by a quantity of electricity equal to 1 C.

Electric conductance	The *siemens* (S) is the electric conductance of a conductor in which a current of 1 A is produced by an electric potential difference of 1 V.
Electric inductance	The *henry* (H) is the inductance of a closed circuit in which an electromotive force of 1 V is produced when the electric current in the circuit varies uniformly at a rate of 1 A/s.
Electric potential difference, electromotive force	The *volt* (V) is the difference of electric potential between two points of a conductor carrying a constant current of 1 A when the power dissipated between these points is equal to 1 W.
Electric resistance	The *ohm* (Ω) is the electric resistance between two points of a conductor when a constant difference of potential of 1 V, applied between these two points, produces in this conductor a current of 1 A, this conductor not being the source of any electromotive force.
Energy	The *joule* (J) is the work done when the point of application of a force of 1 N is displaced a distance of 1 m in the direction of the force.
Force	The *newton* (N) is that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/s^2.
Frequency	The *hertz* (Hz) is the frequency of a periodic phenomenon of which the period is 1 second.
Illuminance	The *lux* (lx) is the illuminance produced by a luminous flux of 1 lm uniformly distributed over a surface of 1 m^2.
Luminous flux	The *lumen* (lm) is the luminous flux emitted in a solid angle of 1 sr by a point source having a uniform intensity of 1 cd.
Magnetic flux	The *weber* (Wb) is the magnetic flux which, linking a circuit of one turn, produces in it an electromotive force of 1 V as it is reduced to zero at a uniform rate in 1 s.
Magnetic flux density magnetic induction	The *tesla* (T) is the magnetic flux density of 1 Wb/m^2. In an alternative approach to defining the magnetic field quantities the *tesla* may also be defined as the magnetic flux density that produces on a 1-m length of wire carrying a current of 1 A, oriented normal to the flux density, a force of 1 N, magnetic flux density being defined as an axial vector quantity such that the force exerted on an element of current is equal to the vector product of this element and the magnetic flux density.
Power	The *watt* (W) is the power that represents a rate of energy transfer of 1 J/s.
Pressure or stress	The *pascal* (Pa) is the pressure or stress of 1 N/m^2.
Electric charge, quantity of electricity	*Electric charge* is the time integral of electric current; its unit, the *coulomb* (C), is equal to 1 A·s.

No other SI derived units have been assigned special names at this time.

APPENDIX C[3,8]*

Style Guide for Metric Usage

Rules for Writing Metric Quantities

Capitals. *Units*—Unit names, including prefixes, are not capitalized except at the beginning of a sentence or in titles. Note that for "degree Celsius" the word "degree" is lower case; the modifier "Celsius" is always capitalized. The "degree centrigrade" is now obsolete.

Symbols—The short forms for metric units are called unit symbols. They are lower case except that the first letter is upper case when the unit is named for a person. (An exception to this rule in the U.S. is the symbol L for liter.)

Examples:

Unit Name	Unit Symbol
meter**	m
gram	g
newton	N
pascal	Pa

Printed unit symbols should have Roman (upright) letters, because italic (sloping or slanted) letters are reserved for quantity symbols, such as *m* for mass and *L* for length.

Prefix Symbols—All prefix names, their symbols, and pronunciation are listed in Table 1.4. Notice that the top five are upper case and all the rest lower case.

The importance of following the precise use of uppercase and lower-case letters is shown by the following examples of prefixes and units.

G for giga; g for gram.
K for kelvin; k for kilo.
M for mega; m for milli.
N for newton; n for nano.
T for tera; t for tonne (metric ton).

Information Processing—Limited Character Sets—Prefixes and unit symbols retain their prescribed forms regardless of the surrounding typography, except for systems with limited character sets. ISO has provided a standard[12] for such systems; this standard is recommended.

Plurals and Fractions. Names of SI units form their plurals in the usual manner, except for lux, hertz, and siemens.

Values less than one take the singular form of the unit name; for example, 0.5 kilogram or ½ kilogram. While decimal notation (0.5, 0.35, 6.87) is generally preferred, the most simple fractions are acceptable, such as those where the denominator is 2, 3, 4, or 5.

Symbols of units are the same in singular and plural—e.g., 1 m and 100 m.

Periods. A period is *not* used after a symbol, except at the end of a sentence. Examples: "A current of 15 mA is found..." "The field measured 350 × 125 m."

The Decimal Marker. ISO specifies the comma as the decimal marker[9]; in English-language documents a dot *on* the line is acceptable. In numbers less than one, a zero should be written before the decimal sign (to prevent the possibility that a faint decimal sign will be overlooked). Example: The oral expression "point seven five" is written 0.75 or 0,75.

Grouping of Numbers. Separate digits into groups of three, counting from the decimal marker. *A comma should not be used between the groups of three*[9]; instead, a space is left to avoid confusion, since the comma is the ISO standard for the decimal marker.

In a four-digit number, the space is not required unless the four-digit number is in a column with numbers of five digits or more:

For	4,720,525	write	4 720 525
For	0.52875	write	0.528 75
For	6,875	write	6875 or 6 875
For	0.6875	write	0.6875 or 0.687 5

*Ref. 8 is primary source.

**The spellings "metre" and "litre" are preferred by ISO but "meter" and "liter" are official U.S. government spellings.

Spacing. In symbols or names for units having prefixes, no space is left between letters making up the symbol or the name. Examples are kA, kiloampere; and mg, milligram.

When a symbol follows a number to which it refers, a space must be left between the number and the symbol, except when the symbol (such as °) appears in the superscript position. Examples: 455 kHz, 22 mg, 20 mm, 10^6 N, 30 K, 20°C.

When a quantity is used as an adjective, a hyphen should be used between the number and the symbol (except °C). Examples: It is a 35-mm film; the film width is 35 mm. I bought a 6-kg turkey; the turkey weighs 6 kg.

Leave a space on each side of signs for multiplication, division, addition, and subtraction, except within a compound symbol. Examples: 4 cm × 3 m (not 4 cm×3 m); kg/m^3; N·m.

Powers. For unit *names,* use the modifier *squared* or *cubed* after the unit name (except for area and volume)—e.g., meter per second squared. For area or volume, place a modifier before the unit name, including in derived units:—e.g., cubic meter and watt per square meter.

For unit *symbols*, write the symbol for the unit followed by the power superscript—e.g., 14 m^2 and 26 cm^3.

Compound Units. For a unit name (not a symbol) derived as a quotient (e.g., for kilometers per hour), it is preferable not to use a slash (/) as a substitute for "per" except where space is limited and a symbol might not be understood. Avoid other mixtures of words and symbols. Examples: Use meter per second, not m/s. Use only one "per" in any combination of units—e.g., meter per second squared, not meter per second per second.

For a unit symbol derived as a quotient do not, for example, write k.p.h. or kph for km/h because the first two are understood only in the English language, whereas km/h is used in all languages. The symbol km/h also can be written with a negative exponent—e.g., $km \cdot h^{-1}$.

Never use more than one slash (/) in any combination of symbols unless parentheses are used to avoid ambiguity; examples are m/s^2, not m/s/s; W/(m·K), not W/m/K.

For a unit *name* derived as a product, a space or a hyphen is recommended but never a "product dot" (a period raised to a centered position)—e.g., write newton meter or newton-meter, not newton · meter. In the case of the watt hour, the space may be omitted—watthour.

For a unit *symbol* derived as a product, use a product dot—e.g., N·m. For computer printouts, automatic typewriter work, etc., a dot on the line may be used. Do *not* use the product dot as a multiplier symbol for calculations—e.g., use 6.2×5, not 6.2·5.

Do not mix nonmetric units with metric units, except those for time, plane angle, or rotation—e.g., use kg/m^3, not kg/ft^3 or kg/gal.

A quantity that constitutes a ratio of two like quantities should be expressed as a fraction (either common or decimal) or as a percentage—e.g., the slope is 1/100 or 0.01 or 1%, not 10 mm/m or 10 m/km.

SI Prefix Usage. *General*—SI prefixes should be used to indicate orders of magnitude, thus eliminating nonsignificant digits and leading zeros in decimal fractions and providing a convenient alternative to the powers-of-10 notation preferred in computation. For example, 12 300 m (in computations) becomes 12.3 km (in noncomputation situations); 0.0123 μA (12.3×10^{-9} A for computations) becomes 12.3 nA (in noncomputation situations).

Selection—When expressing a quantity by a numerical value and a unit, prefixes should be chosen so that the numerical value lies between 0.1 and 1000. Generally, prefixes representing steps of 1000 are recommended (avoiding hecto, deka, deci, and centi). However, some situations may justify deviation from the above:

1. In expressing units raised to powers (such as area, volume and moment) the prefixes hecto, deka, deci, and centi may be required—e.g., cubic centimeter for volume and cm^4 for moment.

2. In tables of values of the same quantity, or in a discussion of such values within a given context, it generally is preferable to use the same unit multiple throughout.

3. For certain quantities in particular applications, one certain multiple is used customarily; an example is the millimeter in mechanical engineering drawings, even when the values lie far outside the range of 0.1 to 1000 mm.

Powers of Units—An exponent attached to a symbol containing a prefix indicates that *the multiple or submultiple of the unit* (the unit with its prefix) *is raised to the power expressed by the exponent.* For example,

$1\ cm^3$	$=(10^{-2} m)^3$	$=10^{-6} m^3$
$1\ ns^{-1}$	$=(10^{-9} s)^{-1}$	$=10^9 s^{-1}$
$1\ mm^2/s$	$=(10^{-3} m)^2/s$	$=10^{-5} m^2/s$

Double Prefixes—Double or multiple prefixes should not be used. For example,

use GW (gigawatt), not kMW;
use pm (picometer), not μμm;
use Gg (gigagram), not Mkg;
use 13.58 m, not 13 m 580 mm.

Prefix Mixtures—Do not use a mixture of prefixes unless the difference in size is extreme. For example, use 40 mm wide and 1500 mm long, not 40 mm wide and 1.5 m long; however, 1500 m of 2-mm-diameter wire is acceptable.

Compound Units—It is *preferable* that prefixes not be used in the denominators of complex units, except for kilogram (kg) which is a base unit. However, there are cases where the use of such prefixes is necessary to obtain a numerical value of convenient size. Examples of some of these rare exceptions are shown in the tables contained in these standards.

Prefixes may be applied to the numerator of a compound unit; thus, megagram per cubic meter (Mg/m^3), but *not* kilogram per cubic decimeter (kg/dm^3) *nor* gram per cubic centimeter (g/cm^3). Values required outside the range of the prefixes should be expressed by powers of 10 applied to the base unit.

Unit of Mass—Among the base units of SI, the kilogram is the only one whose name, for historical reasons, contains a prefix; it is also the coherent SI unit for mass (See Appendices A and B for discussions of coherence.) However, names of decimal multiples and submultiples of the unit of mass are formed by attaching prefixes to the word "gram."

Prefixes Alone—Do not use a prefix without a unit—e.g., use kilogram, not kilo.

Calculations—Errors in calculations can be minimized if, instead of using prefixes, the *base* and the *coherent* derived SI units are used, expressing numerical values in powers-of-10 notation—e.g., $1\ MJ=10^6\ J$.

Spelling of Vowel Pairs. There are three cases where the final vowel in a prefix is omitted: megohm, kilohm, and hectare. In all other cases, both vowels are retained and both are pronounced. No space or hyphen should be used.

Complicated Expressions. To avoid ambiguity in complicated expressions, symbols are preferred over words.

Attachment. Attachment of letters to a unit symbol for giving information about the nature of the quantity is incorrect: MWe for "megawatts electrical (power)," kPag for "kilopascals gauge (pressure)," Paa for "pascals absolute (pressure)," and Vac for "volts ac" are not acceptable. If the context is in doubt on any units used, supplementary descriptive phrases should be added to making the meanings clear.

Equations. When customary units appear in equations, the SI equivalents should be omitted. Instead of inserting the latter in parentheses, as in the case of text or small tables, the equations should be restated using SI unit symbols, or a sentence, paragraph, or note should be added stating the factor to be used to convert the calculated result in customary units to the preferred SI units.

Pronunciation of Metric Terms

The pronunciation of most of the unit names is well known and uniformly described in American dictionaries, but four have been pronounced in various ways. The following pronunciations are recommended:

candela	— Accent on the second syllable and pronounce it like *dell.*
joule	— Pronounce it to rhyme with *pool.*
pascal	— The preferred pronunciation rhymes with *rascal.* An acceptable second choice puts the accent on the second syllable.
siemens	— Pronounce it like *seamen's.*

For pronunciation of unit prefixes, see Table 1.4.

Typewriting Recommendations

Superscripts. The question arises of how numerical superscripts should be typed on a machine with a conventional keyboard. With an ordinary keyboard, numerals and the minus sign can be raised to the superscript position by rolling the platen half a space before typing the numeral, using care to avoid interference with the text in the line above.

Special Characters. For technical work, it is useful to have Greek letters available on the typewriter. If all SI symbols for units are to be typed properly, a key with the upright Greek lower-case μ (pronounced "mew," not "moo") is necessary, since this is the symbol for micro, meaning one millionth. The symbol can be approximated on a conventional machine by using a lower-case u and adding the tail by hand (μ). A third choice is to spell out the unit name in full.

For units of electricity, the Greek upper case omega (Ω) for ohm also will be useful; when it is not available, the word "ohm" can be spelled out.

It is fortunate that, except for the more extensive use of the Greek μ for micro and Ω for ohm, the change to SI units causes no additional difficulty in manuscript preparation.

The Letter for Liter. On most U.S. typewriters, there is little difference between the lower-case "el" ("l") and the numerical "one" ("1"). The European symbol for liter is a simple upright bar; the Canadians[13] employed an upright script ℓ but now have adopted the upright capital L; ANSI now recommends the upright capital L.

Typewriter Modification. Where frequently used, the following symbols could be included on typewriters: superscripts ^{2} and ^{3} for squared and cubed; Greek μ for micro; ° for degree; · for a product dot (not a period) for symbols derived as a product; and Greek Ω for ohm.

A special type-ball that contains all the superscripts, μ, Ω, and other characters used in technical reports is vailable for some typewriters. Some machines have replaceable character keys.

Longhand. To assure legibility of the symbols, m, n, and μ, it is recommended that these three symbols be written to resemble printing. For example, write nm, not *nm*. The symbol μ should have a long distinct tail and should have the upright form (not sloping or italic).

Shorthand. Stenographers will find that the SI symbols generally are quicker to write than the shorthand forms for the unit names.

APPENDIX D
General Conversion Factors*

General

The accompanying Table 1.7 is intended to serve two purposes:

1. To express the definitions of general units of measure as exact numerical multiples of coherent "metric" units. Relationships that are exact in terms of the fundamental SI unit are followed by an asterisk. Relationships that are not followed by an asterisk either are the result of physical measurements or are only approximate.
2. To provide multiplying factors for converting expressions of measurements given by numbers and general or miscellaneous units to corresponding new numbers and metric units.

*Based on ASTM Pub. E380-82 (Ref. 3); values of conversion factors tabulated herewith are identical with those in E380-82; generally similar material is found in Ref. 4. Conversion values in earlier editions of E 380 (for example, E 380-74) are based on Ref. 15, which has available some factors with more than seven digits.

Notation

Conversion factors are presented for ready adaptation to computer readout and electronic data transmission. The factors are written as a number equal to or greater than one and less than 10, with six or fewer decimal places (i.e., seven or fewer total digits). Each number is followed by the letter E (for exponent), a plus or minus symbol, and two digits that indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example,

3.523 907 (E−02) is $3.523\ 907 \times 10^{-2}$

or

0.035 239 07.

Similarly,

3.386 389 (E+03) is $3.386\ 389 \times 10^{3}$

or

3 386.389.

An asterisk (*) after the numbers shown indicates that the conversion factor is exact and that all subsequent digits (for rounding purposes) are zero. All other conversion factors have been rounded to the figures given in accordance with procedures outlined in the preceding text. Where less than six decimal places are shown, more precision is not warranted.

The following is a further example of the use of Table 1.7.

To Convert From	To	Multiply By
pound-force per square foot	Pa	4.788 026 E+01
pound-force per square inch	Pa	6.894 757 E+03
inch	m	2.540* E−02

These conversions mean

1 lbf/ft^2 becomes 47.880 26 Pa,
1 lbf/in.^{2} becomes 6.894.757 Pa or
6.894 757 kPa, and
1 inch becomes 0.0254 m (exactly).

The unit symbol for pound-force sometimes is written lbf and sometimes lb_f or lb_{f}; the form lbf is recommended.

Organization

The conversion factors generally are listed alphabetically by units having specific names and compound units derived from these specific units. A number of units starting with the pound symbol (lb) are located in the "p" section of the list.

Conversion factors classified by physical quantities are listed in Refs. 3 and 4.

The conversion factors for other compound units can be generated easily from numbers given in the alphabetical list by substitution of converted units. For example:

1. Find the conversion factor for productivity index, (B/D)/(lbf/in.^{2}) to (m^3/d)/Pa. Convert 1 B/D to 1.589 873 (E−01) m^3/d and 1 lbf/in.^{2} to 6.894 757 (E+03) Pa. Then, substitute

[1.589 873 (E−01)]/[6.894 757 (E−03)]
=2.305 916 (E−05) (m^3/d)/Pa.

2. Find the conversion factor for tonf·mile/ft to MJ/m. Convert 1 tonf to 8.896 444 (E+03) N; 1 mile to 1.609 344* (E+03) m; and 1 ft to 3.048* (E−01) m. Then, substitute

[8.896 444 (E+03)] [1.609 344 (E+03)]
÷[3.048 (E−01)]
=4.697 322 (E+07) (N·m)/m or J/m
=4.697 322 (E+01) MJ/m.

When conversion factors for complex compound units are being calculated from Table 1.7, numerical uncertainties may be present in the seventh (or lesser last "significant") digit of the answer because of roundings already taken for the last digit of tabulated values. Mechtly[15] provides conversion factors of more than seven digits for certain quantities.

TABLE 1.7—ALPHABETICAL LIST OF UNITS (symbols of SI units given in parentheses)

To Convert From	To	Multiply By**	
abampere	ampere (A)	1.0*	E+01
abcoulomb	coulomb (C)	1.0*	E+01
abfarad	farad (F)	1.0*	E+09
abhenry	henry (H)	1.0*	E−09
abmho	siemens (S)	1.0*	E+09
abohm	ohm (Ω)	1.0*	E−09
abvolt	volt (V)	1.0*	E−08
acre·foot (U.S. survey)(1)	meter^3 (m^3)	1.233 489	E+03
acre (U.S. survey)(1)	meter^2 (m^2)	4.046 873	E+03
ampere hour	coulomb (C)	3.6*	E+03
are	meter^2 (m^2)	1.0*	E+02
angstrom	meter (m)	1.0*	E−10
astronomical unit	meter (m)	1.495 979	E+11
atmosphere (standard)	pascal (Pa)	1.013 250*	E+05
atmosphere (technical = 1 kgf/cm^2)	pascal (Pa)	9.806 650*	E+04
bar	pascal (Pa)	1.0*	E+05
barn	meter^2 (m^2)	1.0*	E−28
barrel (for petroleum, 42 gal)	meter^3 (m^3)	1.589 873	E−01
board foot	meter^3 (m^3)	2.359 737	E−03
British thermal unit (International Table)(2)	joule (J)	1.055 056	E+03
British thermal unit (mean)	joule (J)	1.055 87	E+03
British thermal unit (thermochemical)	joule (J)	1.054 350	E+03
British thermal unit (39°F)	joule (J)	1.059 67	E+03
British thermal unit (59°F)	joule (J)	1.054 80	E+03
British thermal unit (60°F)	joule (J)	1.054 68	E+03
Btu (International Table)-ft/(hr-ft^2-°F) (thermal conductivity)	watt per meter kelvin [W/(m·K)]	1.730 735	E+00
Btu (thermochemical)-ft/(hr-ft^2-°F) (thermal conductivity)	watt per meter kelvin [W/(m·K)]	1.729 577	E+00
Btu (International Table)-in./(hr-ft^2-°F) (thermal conductivity)	watt per meter kelvin [W/(m·K)]	1.442 279	E−01
Btu (thermochemical)-in./(hr-ft^2-°F) (thermal conductivity)	watt per meter kelvin [W/(m·K)]	1.441 314	E−01
Btu (International Table)-in./(s-ft^2-°F) (thermal conductivity)	watt per meter kelvin [W/(m·K)]	5.192 204	E+02
Btu (thermochemical)-in./(s-ft^2-°F) (thermal conductivity)	watt per meter kelvin [W/(m·K)]	5.188 732	E+02
Btu (International Table)/hr	watt (W)	2.930 711	E−01
Btu (thermochemical)/hr	watt (W)	2.928 751	E−01
Btu (thermochemical)/min	watt (W)	1.757 250	E+01
Btu (thermochemical)/s	watt (W)	1.054 350	E+03
Btu (International Table)/ft^2	joule per meter^2 (J/m^2)	1.135 653	E+04
Btu (thermochemical)/ft^2	joule per meter^2 (J/m^2)	1.134 893	E+04
Btu (thermochemical)/(ft^2-hr)	watt per meter^2 (W/m^2)	3.152 481	E+00
Btu (thermochemical)/(ft^2-min)	watt per meter^2 (W/m^2)	1.891 489	E+02
Btu (thermochemical)/(ft^2-s)	watt per meter^2 (W/m^2)	1.134 893	E+04
Btu (thermochemical)/(in.^{2}-s)	watt per meter^2 (W/m^2)	1.634 246	E+06
Btu (International Table)/(hr-ft^2-°F) (thermal conductance)	watt per meter^2 kelvin [W/(m^2·K)]	5.678 263	E+00
Btu (thermochemical)/(hr-ft^2-°F) (thermal conductance)	watt per meter^2 kelvin [W/(m^2·K)]	5.674 466	E+00
Btu (International Table)/(s-ft^2-°F)	watt per meter^2 kelvin [W/(m^2·K)]	2.044 175	E+04
Btu (thermochemical)/(s-ft^2-°F)	watt per meter^2 kelvin [W/(m^2·K)]	2.042 808	E+04
Btu (International Table)/lbm	joule per kilogram (J/kg)	2.326*	E+03
Btu (thermochemical)/lbm	joule per kilogram (J/kg)	2.324 444	E+03
Btu (International Table)/(lbm-°F) (heat capacity)	joule per kilogram kelvin [J/(kg·K)]	4.186 8*	E+03
Btu (thermochemical)/(lbm-°F) (heat capacity)	joule per kilogram kelvin [J/(kg·K)]	4.184 000	E+03

**See footnote on Page 13.

(1)Since 1893 the U.S. basis of length measurement has been derived from metric standards. In 1959 a small refinement was made in the definition of the yard to resolve discrepancies both in this country and abroad, which changed its length from 3600/3937 m to 0.9144 m exactly. This resulted in the new value being shorter by two parts in a million. At the same time it was decided that any data in feet derived from and published as a result of geodetic surveys within the U.S. would remain with the old standard (1 ft = 1200/3937 m) until further decision. This foot is named the U.S. survey foot. As a result, all U.S. land measurements in U.S. customary units will relate to the meter by the old standard. All the conversion factors in these tables for units referenced to this footnote are based on the U.S. survey foot, rather than the international foot. Conversion factors for the land measure given below may be determined from the following relationships:

1 league = 3 miles (exactly)
1 rod = 16½ ft (exactly)
1 chain = 66 ft (exactly)
1 section = 1 sq mile
1 township = 36 sq miles

(2)This value was adopted in 1956. Some of the older International Tables use the value 1.055 04 E+03. The exact conversion factor is 1.055 055 852 62* E+03.

TABLE 1.7—ALPHABETICAL LIST OF UNITS (cont'd.)
(symbols of SI units given in parentheses)

To Convert From	To	Multiply By**	
bushel (U.S.)	meter³ (m³)	3.523 907	E−02
caliber (inch)	meter (m)	2.54*	E−02
calorie (International Table)	joule (J)	4.186 8*	E+00
calorie (mean)	joule (J)	4.190 02	E+00
calorie (thermochemical)	joule (J)	4.184*	E+00
calorie (15°C)	joule (J)	4.185 80	E+00
calorie (20°C)	joule (J)	4.181 90	E+00
calorie (kilogram, International Table)	joule (J)	4.186 8*	E+03
calorie (kilogram, mean)	joule (J)	4.190 02	E+03
calorie (kilogram, thermochemical)	joule (J)	4.184*	E+03
cal (thermochemical)/cm²	joule per meter² (J/m²)	4.184*	E+04
cal (International Table)/g	joule per kilogram (J/kg)	4.186*	E+03
cal (thermochemical)/g	joule per kilogram (J/kg)	4.184*	E+03
cal (International Table)/(g·°C)	joule per kilogram kelvin [J/(kg·K)]	4.186 8*	E+03
cal (thermochemical)/(g·°C)	joule per kilogram kelvin [J/(kg·K)]	4.184*	E+03
cal (thermochemical)/min	watt (W)	6.973 333	E−02
cal (thermochemical)/s	watt (W)	4.184*	E+00
cal (thermochemical)/(cm²·min)	watt per meter² (W/m²)	6.973 333	E+02
cal (thermochemical)/(cm²·s)	watt per meter² (W/m²)	4.184*	E+04
cal (thermochemical)/(cm·s·°C)	watt per meter kelvin [W/(m·K)]	4.184*	E+02
capture unit (c.u. = 10^{-3} cm^{-1})	per meter (m^{-1})	1.0*	E−01
carat (metric)	kilogram (kg)	2.0*	E−04
centimeter of mercury (0°C)	pascal (Pa)	1.333 22	E+03
centimeter of water (4°C)	pascal (Pa)	9.806 38	E+01
centipoise	pascal second (Pa·s)	1.0*	E−03
centistokes	meter² per second (m²/s)	1.0*	E−06
circular mil	meter² (m²)	5.067 075	E−10
clo	kelvin meter² per watt [(K·m²)/W]	2.003 712	E−01
cup	meter³ (m³)	2.365 882	E−04
curie	becquerel (Bq)	3.7*	E+10
cycle per second	hertz (Hz)	1.0*	E+00
day (mean solar)	second (s)	8.640 000	E+04
day (sidereal)	second (s)	8.616 409	E+04
degree (angle)	radian (rad)	1.745 329	E−02
degree Celsius	kelvin (K)	$T_K = T_{°C} + 273.15$	
degree centigrade (see degree Celsius)			
degree Fahrenheit	degree Celsius	$T_{°C} = (T_{°F} - 32)/1.8$	
degree Fahrenheit	kelvin (K)	$T_K = (T_{°F} + 459.67)/1.8$	
degree Rankine	kelvin (K)	$T_K = T_{°R}/1.8$	
°F·hr-ft²/Btu (International Table) (thermal resistance)	kelvin meter² per watt [(K·m²)/W]	1.781 102	E−01
°F·hr-ft²/Btu (thermochemical) (thermal resistance)	kelvin meter² per watt [(K·m²)/W]	1.762 250	E−01
denier	kilogram per meter (kg/m)	1.111 111	E−07
dyne	newton (N)	1.0*	E−05
dyne·cm	newton meter (N·m)	1.0*	E−07
dyne/cm²	pascal (Pa)	1.0*	E−01
electronvolt	joule (J)	1.602 19	E−19
EMU of capacitance	farad (F)	1.0*	E+09
EMU of current	ampere (A)	1.0*	E+01
EMU of electric potential	volt (V)	1.0*	E−08
EMU of inductance	henry (H)	1.0*	E−09
EMU of resistance	ohm (Ω)	1.0*	E−09
ESU of capacitance	farad (F)	1.112 650	E−12
ESU of current	ampere (A)	3.335 6	E−10
ESU of electric potential	volt (V)	2.997 9	E+02
ESU of inductance	henry (H)	8.987 554	E+11
ESU of resistance	ohm (Ω)	8.987 554	E+11
erg	joule (J)	1.0*	E−07
erg/cm²·s	watt per meter² (W/m²)	1.0*	E−03
erg/s	watt (W)	1.0*	E−07
faraday (based on carbon-12)	coulomb (C)	9.648 70	E+04
faraday (chemical)	coulomb (C)	9.649 57	E+04
faraday (physical)	coulomb (C)	9.652 19	E+04
fathom	meter (m)	1.828 8	E+00
fermi (femtometer)	meter (m)	1.0*	E−15
fluid ounce (U.S.)	meter³ (m³)	2.957 353	E−05
foot	meter (m)	3.048*	E−01
foot (U.S. survey)[(1)]	meter (m)	3.048 006	E−01

TABLE 1.7—ALPHABETICAL LIST OF UNITS (cont'd.)
(symbols of SI units given in parentheses)

To Convert From	To	Multiply By**
foot of water (39.2°F)	pascal (Pa)	2.988 98 E+03
sq ft	meter² (m²)	9.290 304* E−02
ft²/hr (thermal diffusivity)	meter² per second (m²/s)	2.580 640* E−05
ft²/s	meter² per second (m²/s)	9.290 304* E−02
cu ft (volume; section modulus)	meter³ (m³)	2.831 685 E−02
ft³/min	meter³ per second (m³/s)	4.719 474 E−04
ft³/s	meter³ per second (m³/s)	2.831 685 E−02
ft⁴ (moment of section)(3)	meter⁴ (m⁴)	8.630 975 E−03
ft/hr	meter per second (m/s)	8.466 667 E−05
ft/min	meter per second (m/s)	5.080* E−03
ft/s	meter per second (m/s)	3.048* E−01
ft/s²	meter per second² (m/s²)	3.048* E−01
footcandle	lux (lx)	1.076 391 E+01
footlambert	candela per meter² (cd/m²)	3.426 259 E+00
ft-lbf	joule (J)	1.355 818 E+00
ft-lbf/hr	watt (W)	3.766 161 E−04
ft-lbf/min	watt (W)	2.259 697 E−02
ft-lbf/s	watt (W)	1.355 818 E+00
ft-poundal	joule (J)	4.214 011 E−02
free fall, standard (*g*)	meter per second² (m/s²)	9.806 650* E+00
cm/s²	meter per second² (m/s²)	1.0* E−02
gallon (Canadian liquid)	meter³ (m³)	4.546 090 E−03
gallon (U.K. liquid)	meter³ (m³)	4.546 092 E−03
gallon (U.S. dry)	meter³ (m³)	4.404 884 E−03
gallon (U.S. liquid)	meter³ (m³)	3.785 412 E−03
gal (U.S. liquid)/day	meter³ per second (m³/s)	4.381 264 E−08
gal (U.S. liquid)/min	meter³ per second (m³/s)	6.309 020 E−05
gal (U.S. liquid)/hp·hr (SFC, specific fuel consumption)	meter³ per joule (m³/J)	1.410 089 E−09
gamma (magnetic field strength)	ampere per meter (A/m)	7.957 747 E−04
gamma (magnetic flux density)	tesla (T)	1.0* E−09
gauss	tesla (T)	1.0* E−04
gilbert	ampere (A)	7.957 747 E−01
gill (U.K.)	meter³ (m³)	1.420 654 E−04
gill (U.S.)	meter³ (m³)	1.182 941 E−04
grad	degree (angular)	9.0* E−01
grad	radian (rad)	1.570 796 E−02
grain (1/7000 lbm avoirdupois)	kilogram (kg)	6.479 891* E−05
grain (lbm avoirdupois/7000)/gal (U.S. liquid)	kilogram per meter³ (kg/m³)	1.711 806 E−02
gram	kilogram (kg)	1.0* E−03
g/cm³	kilogram per meter³ (kg/m³)	1.0* E+03
gram-force/cm²	pascal (Pa)	9.806 650* E+01
hectare	meter² (m²)	1.0* E+04
horsepower (550 ft-lbf/s)	watt (W)	7.456 999 E+02
horsepower (boiler)	watt (W)	9.809 50 E+03
horsepower (electric)	watt (W)	7.460* E+02
horsepower (metric)	watt (W)	7.354 99 E+02
horsepower (water)	watt (W)	7.460 43 E+02
horsepower (U.K.)	watt (W)	7.457 0 E+02
hour (mean solar)	second (s)	3.600 000 E+03
hour (sidereal)	second (s)	3.590 170 E+03
hundredweight (long)	kilogram (kg)	5.080 235 E+01
hundredweight (short)	kilogram (kg)	4.535 924 E+01
inch	meter (m)	2.54* E−02
inch of mercury (32°F)	pascal (Pa)	3.386 38 E+03
inch of mercury (60°F)	pascal (Pa)	3.376 85 E+03
inch of water (39.2°F)	pascal (Pa)	2.490 82 E+02
inch of water (60°F)	pascal (Pa)	2.488 4 E+02
sq in.	meter² (m²)	6.451 6* E−04
cu in. (volume; section modulus)(4)	meter³ (m³)	1.638 706 E−05
in.³/min	meter³ per second (m³/s)	2.731 177 E−07
in.⁴ (moment of section)(3)	meter⁴ (m⁴)	4.162 314 E−07
in./s	meter per second (m/s)	2.54* E−02
in./s²	meter per second² (m/s²)	2.54* E−02
kayser	1 per meter (1/m)	1.0* E+02
kelvin	degree Celsius	$T_{°C} = T_K - 273.15$

(3) This sometimes is called the moment of inertia of a plane section about a specified axis.
(4) The exact conversion factor is 1.638 706 4*E−05.

TABLE 1.7—ALPHABETICAL LIST OF UNITS (cont'd.)
(symbols of SI units given in parentheses)

To Convert From	To	Multiply By**
kilocalorie (International Table)	joule (J)	4.186 8* E+03
kilocalorie (mean)	joule (J)	4.190 02 E+03
kilocalorie (thermochemical)	joule (J)	4.184* E+03
kilocalorie (thermochemical)/min	watt (W)	6.973 333 E+01
kilocalorie (thermochemical)/s	watt (W)	4.184* E+03
kilogram-force (kgf)	newton (N)	9.806 65* E+00
kgf·m	newton meter (N·m)	9.806 65* E+00
kgf·s²/m (mass)	kilogram (kg)	9.806 65* E+00
kgf/cm²	pascal (Pa)	9.806 65* E+04
kgf/m²	pascal (Pa)	9.806 65* E+00
kgf/mm²	pascal (Pa)	9.806 65* E+06
km/h	meter per second (m/s)	2.777 778 E−01
kilopond	newton (N)	9.806 65* E+00
kilowatthour (kW-hr)	joule (J)	3.6* E+06
kip (1000 lbf)	newton (N)	4.448 222 E+03
kip/in.² (ksi)	pascal (Pa)	6.894 757 E+06
knot (international)	meter per second (m/s)	5.144 444 E−01
lambert	candela per meter² (cd/m²)	1/π* E+04
lambert	candela per meter² (cd/m²)	3.183 099 E+03
langley	joule per meter² (J/m²)	4.184* E+04
league	meter (m)	(see Footnote 1)
light year	meter (m)	9.460 55 E+15
liter[5]	meter³ (m³)	1.0* E−03
maxwell	weber (Wb)	1.0* E−08
mho	siemens (S)	1.0* E+00
microinch	meter (m)	2.54* E−08
microsecond/foot (μs/ft)	microsecond/meter (μs/m)	3.280 840 E+00
micron	meter (m)	1.0* E−06
mil	meter (m)	2.54* E−05
mile (international)	meter (m)	1.609 344* E+03
mile (statute)	meter (m)	1.609 3 E+03
mile (U.S. survey)[1]	meter (m)	1.609 347 E+03
mile (international nautical)	meter (m)	1.852* E+03
mile (U.K. nautical)	meter (m)	1.853 184* E+03
mile (U.S. nautical)	meter (m)	1.852* E+03
sq mile (international)	meter² (m²)	2.589 988 E+06
sq mile (U.S. survey)[1]	meter² (m²)	2.589 998 E+06
mile/hr (international)	meter per second (m/s)	4.470 4* E−01
mile/hr (international)	kilometer per hour (km/h)	1.609 344* E+00
mile/min (international)	meter per second (m/s)	2.682 24* E+01
mile/s (international)	meter per second (m/s)	1.609 344* E+03
millibar	pascal (Pa)	1.0* E+02
millimeter of mercury (0°C)	pascal (Pa)	1.333 22 E+02
minute (angle)	radian (rad)	2.908 882 E−04
minute (mean solar)	second (s)	6.0* E+01
minute (sidereal)	second (s)	5.983 617 E+01
month (mean calendar)	second (s)	2.628 000 E+06
oersted	ampere per meter (A/m)	7.957 747 E+01
ohm centimeter	ohm meter (Ω·m)	1.0* E−02
ohm circular-mil per ft	ohm millimeter² per meter [(Ω·mm²)m]	1.662 426 E−03
ounce (avoirdupois)	kilogram (kg)	2.834 952 E−02
ounce (troy or apothecary)	kilogram (kg)	3.110 348 E−02
ounce (U.K. fluid)	meter³ (m³)	2.841 307 E−05
ounce (U.S. fluid)	meter³ (m³)	2.957 353 E−05
ounce-force	newton (N)	2.780 139 E−01
ozf·in.	newton meter (N·m)	7.061 552 E−03
oz (avoirdupois)/gal (U.K. liquid)	kilogram per meter³ (kg/m³)	6.236 021 E+00
oz (avoirdupois)/gal (U.S. liquid)	kilogram per meter³ (kg/m³)	7.489 152 E+00
oz (avoirdupois)/in.³	kilogram per meter³ (kg/m³)	1.729 994 E+03
oz (avoirdupois)/ft²	kilogram per meter² (kg/m²)	3.051 517 E−01
oz (avoirdupois)/yd²	kilogram per meter² (kg/m²)	3.390 575 E−02
parsec	meter (m)	3.085 678 E+16
peck (U.S.)	meter³ (m³)	8.809 768 E−03
pennyweight	kilogram (kg)	1.555 174 E−03
perm (°C)[6]	kilogram per pascal second meter² [kg/(Pa·s·m²)]	5.721 35 E−11

[5]In 1964 the General Conference on Weights and Measures adopted the name liter as a special name for the cubic decimeter. Prior to this decision the liter differed slightly (previous value, 1.000 028 dm³) and in expression of precision volume measurement this fact must be kept in mind.
[6]Not the same as reservoir "perm."

TABLE 1.7—ALPHABETICAL LIST OF UNITS (cont'd.)
(symbols of SI units given in parentheses)

To Convert From	To	Multiply By**	
perm (23°C)[6]	kilogram per pascal second meter² [kg/(Pa·s·m²)]	5.745 25	E−11
perm·in. (0°C)[7]	kilogram per pascal second meter [kg/(Pa·s·m)]	1.453 22	E−12
perm·in. (23°C)[7]	kilogram per pascal second meter [km/(Pa·s·m)]	1.459 29	E−12
phot	lumen per meter² (lm/m²)	1.0*	E+04
pica (printer's)	meter (m)	4.217 518	E−03
pint (U.S. dry)	meter³ (m³)	5.506 105	E−04
pint (U.S. liquid)	meter³ (m³)	4.731 765	E−04
point (printer's)	meter (m)	3.514 598*	E−04
poise (absolute viscosity)	pascal second (Pa·s)	1.0*	E−01
pound (lbm avoirdupois)[8]	kilogram (kg)	4.535 924	E−01
pound (troy or apothecary)	kilogram (kg)	3.732 417	E−01
lbm-ft² (moment of inertia)	kilogram meter² (kg·m²)	4.214 011	E−02
lbm-in.² (moment of inertia)	kilogram meter² (kg·m²)	2.926 397	E−04
lbm/ft-hr	pascal second (Pa·s)	4.133 789	E−04
lbm/ft-s	pascal second (Pa·s)	1.488 164	E+00
lbm/ft²	kilogram per meter² (kg/m²)	4.882 428	E+00
lbm/ft³	kilogram per meter³ (kg/m³)	1.601 846	E+01
lbm/gal (U.K. liquid)	kilogram per meter³ (kg/m³)	9.977 633	E+01
lbm/gal (U.S. liquid)	kilogram per meter³ (kg/m³)	1.198 264	E+02
lbm/hr	kilogram per second (kg/s)	1.259 979	E−04
lbm/(hp · hr) (SFC, specific fuel consumption)	kilogram per joule (kg/J)	1.689 659	E−07
lbm/in.³	kilogram per meter³ (kg/m³)	2.767 990	E+04
lbm/min	kilogram per second (kg/s)	7.559 873	E−03
lbm/s	kilogram per second (kg/s)	4.535 924	E−01
lbm/yd³	kilogram per meter³ (kg/m³)	5.932 764	E−01
poundal	newton (N)	1.382 550	E−01
poundal/ft²	pascal (Pa)	1.488 164	E+00
poundal-s/ft²	pascal second (Pa·s)	1.488 164	E+00
pound-force (lbf)[9]	newton (N)	4.448 222	E+00
lbf-ft[10]	newton meter (N·m)	1.355 818	E+00
lbf-ft/in.[11]	newton meter per meter [(N·m)/m)]	5.337 866	E+01
lbf-in.[11]	newton meter (N·m)	1.129 848	E−01
lbf-in./in.[11]	newton meter per meter [(N·m)/m]	4.448 222	E+00
lbf-s/ft²	pascal second (Pa·s)	4.788 026	E+01
lbf/ft	newton per meter (N/m)	1.459 390	E+01
lbf/ft²	pascal (Pa)	4.788 026	E+01
lbf/in.	newton per meter (N/m)	1.751 268	E+02
lbf/in.² (psi)	pascal (Pa)	6.894 757	E+03
lbf/lbm (thrust/weight [mass] ratio)	newton per kilogram (N/kg)	9.806 650	E+00
quart (U.S. dry)	meter³ (m³)	1.101 221	E−03
quart (U.S. liquid)	meter³ (m³)	9.463 529	E−04
rad (radiation dose absorbed)	gray (Gy)	1.0*	E−02
rhe	1 per pascal second [1/(Pa·s)]	1.0*	E+01
rod	meter (m)	(see Footnote 1)	
roentgen	coulomb per kilogram (C/kg)	2.58	E−04
second (angle)	radian (rad)	4.848 137	E−06
second (sidereal)	second (s)	9.972 696	E−01
section	meter² (m²)	(see Footnote 1)	
shake	second (s)	1.000 000*	E−08
slug	kilogram (kg)	1.459 390	E+01
slug/(ft-s)	pascal second (Pa·s)	4.788 026	E+01
slug/ft³	kilogram per meter³ (kg/m³)	5.153 788	E+02
statampere	ampere (A)	3.335 640	E−10
statcoulomb	coulomb (C)	3.335 640	E−10
statfarad	farad (F)	1.112 650	E−12
stathenry	henry (H)	8.987 554	E+11
statmho	siemens (S)	1.112 650	E−12
statohm	ohm (Ω)	8.987 554	E+11
statvolt	volt (V)	2.997 925	E+02
stere	meter³ (m³)	1.0*	E+00

(7)Not the same dimensions as "millidarcy-foot."
(8)The exact conversion factor is 4.535 923 7*E−01.
(9)The exact conversion factor is 4.448 221 615 260 5*E+00.
(10)Torque unit; see text discussion of "Torque and Bending Moment."
(11)Torque divided by length; see text discussion of "Torque and Bending Moment."

TABLE 1.7—ALPHABETICAL LIST OF UNITS (cont'd.)
(symbols of SI units given in parentheses)

To Convert From	To	Multiply By**	
stilb	candela per meter² (cd/m²)	1.0*	E+04
stokes (kinematic viscosity)	meter² per second (m²/s)	1.0*	E−04
tablespoon	meter³ (m³)	1.478 676	E−05
teaspoon	meter³ (m³)	4.928 922	E−06
tex	kilogram per meter (kg/m)	1.0*	E−06
therm	joule (J)	1.055 056	E+08
ton (assay)	kilogram (kg)	2.916 667	E−02
ton (long, 2,240 lbm)	kilogram (kg)	1.016 047	E+03
ton (metric)	kilogram (kg)	1.0*	E+03
ton (nuclear equivalent of TNT)	joule (J)	4.184	E+09[12]
ton (refrigeration)	watt (W)	3.516 800	E+03
ton (register)	meter³ (m³)	2.831 685	E+00
ton (short, 2000 lbm)	kilogram (kg)	9.071 847	E+02
ton (long)/yd³	kilogram per meter³ (kg/m³)	1.328 939	E+03
ton (short)/hr	kilogram per second (kg/s)	2.519 958	E−01
ton-force (2000 lbf)	newton (N)	8.896 444	E+03
tonne	kilogram (kg)	1.0*	E+03
torr (mm Hg, 0°C)	pascal (Pa)	1.333 22	E+02
township	meter² (m²)	(see Footnote 1)	
unit pole	weber (Wb)	1.256 637	E−07
watthour (W-hr)	joule (J)	3.60*	E+03
W·s	joule (J)	1.0*	E+00
W/cm²	watt per meter² (W/m²)	1.0*	E+04
W/in.²	watt per meter² (W/m²)	1.550 003	E+03
yard	meter (m)	9.144*	E−01
yd²	meter² (m²)	8.361 274	E−01
yd³	meter³ (m³)	7.645 549	E−01
yd³/min	meter³ per second (m³/s)	1.274 258	E−02
year (calendar)	second (s)	3.153 600	E+07
year (sidereal)	second (s)	3.155 815	E+07
year (tropical)	second (s)	3.155 693	E+07

[12]Defined (not measured) value.

APPENDIX E

TABLE 1.8 — CONVERSION FACTORS FOR THE VARA*

Location	Value of Vara in Inches	Conversion Factor, Varas to Meters		Source
Argentina, Paraguay	34.12	8.666	E−01	Ref. 16
Cadiz, Chile, Peru	33.37	8.476	E−01	Ref. 16
California,				
except San Francisco	33.3720	8.476 49	E−01	Ref. 16
San Francisco	33.0	8.38	E−01	Ref. 16
Central America	33.87	8.603	E−01	Ref. 16
Colombia	31.5	8.00	E−01	Ref. 16
Honduras	33.0	8.38	E−01	Ref. 16
Mexico		8.380	E−01	Refs. 16 and 17
Portugal, Brazil	43.0	1.09	E+00	Ref. 16
Spain, Cuba, Venezuela, Philippine Islands	33.38**	8.479	E−01	Ref. 17
Texas				
Jan. 26, 1801, to Jan. 27, 1838	32.8748	8.350 20	E−01	Ref. 16
Jan. 27, 1838 to June 17, 1919, for surveys of state land made for Land Office	33-1/3	8.466 667	E−01	Ref. 16
Jan. 27, 1838 to June 17, 1919, on private surveys (unless changed to 33-1/3 in. by custom arising to dignity of law and overcoming former law)	32.8748	8.350 20	E−01	Ref. 16
June 17, 1919, to present	33-1/3	8.466 667	E−01	Ref. 16

*It is evident from Ref. 16 that accurate defined lengths of the vara varied significantly, according to historical date and locality used. For work requiring accurate conversions, the user should check closely into the date and location of the surveys involved, with due regard to what local practice may have been at that time and place.
**This value quoted from *Webster's New International Dictionary.*

TABLE 1.9—"MEMORY JOGGER"—METRIC UNITS

Customary Unit	"BallPark" Metric Values; (Do *Not* Use As Conversion Factors)	
acre	4000	square meters
	0.4	hectare
barrel	0.16	cubic meter
British thermal unit	1000	joules
British thermal unit per pound-mass	2300	joules per kilogram
	2.3	kilojoules per kilogram
calorie	4	joules
centipoise	1*	millipascal-second
centistokes	1*	square millimeter per second
darcy	1	square micrometer
degree Fahrenheit (temperature *difference*)	0.5	kelvin
dyne per centimeter	1*	millinewton per meter
foot	30	centimeters
	0.3	meter
cubic foot (cu ft)	0.03	cubic meter
cubic foot per pound-mass (ft^3/lbm)	0.06	cubic meter per kilogram
square foot (sq ft)	0.1	square meter
foot per minute	0.3	meter per minute
	5	millimeters per second
foot-pound-force	1.4	joules
foot-pound-force per minute	0.02	watt
foot-pound-force per second	1.4	watts
horsepower	750	watts (¾ kilowatt)
horsepower, boiler	10	kilowatts
inch	2.5	centimeters
kilowatthour	3.6*	megajoules
mile	1.6	kilometers
ounce (avoirdupois)	28	grams
ounce (fluid)	30	cubic centimeters
pound-force	4.5	newtons
pound-force per square inch (pressure, psi)	7	kilopascals
pound-mass	0.5	kilogram
pound-mass per cubic foot	16	kilograms per cubic meter
section	260	hectares
	2.6	million square meters
	2.6	square kilometers
ton, long (2240 pounds-mass)	1000	kilograms
ton, metric (tonne)	1000*	kilograms
ton, short	900	kilograms

*Exact equivalents

APPENDIX F

Part 2: Discussion of Metric Unit Standards

Introduction

The standards and conventions shown in Part 1 are part of the SPE tentative standards. Table 2.1 presents nomenclature for Tables 2.2 and 2.3. Table 2.2 is a modified form of a table in API 2564 reflecting SPE recommendations. Table 2.3 shows a few units commonly used in the petroleum industry that are not shown in Table 1.7 and 2.2. The columns in these tables are based on the following.

Quantity and SI Unit. The quantity and the base or derived SI unit that describes that quantity.

Customary Unit. The unit most commonly used in expressing the quantity in English units.

SPE Preferred. The base or derived SI unit plus the approved prefix, if any, that probably will be used most commonly to achieve convenient unit size. Any approved prefix may be used in combination with an approved SI unit without violation of these standards except where otherwise noted.

Other Allowable. A small, selected list of non-SI units that are approved *temporarily* for the convenience of the English-metric transition. Use of the allowable units may be discouraged but is not prohibited. Any traditional, non-SI unit not shown is prohibited under these standards.

Conversion Factor. For certain commonly used units, a conversion factor is shown. The primary purpose in these tables is to show how the *preferred metric unit* compares in size with the *traditional unit.* An effort has been made to keep the unit sizes comparable to minimize transition difficulties.

A detailed summary of general conversion factors is included as Table 1.7 in Part 1 of this report.

The notation for conversion factors in Tables 2.2 and 2.3 is explained in the introduction to Table 1.7.

Fig. 2.1 shows graphically how SI units are related in a very coherent manner. Although it may not be readily apparent, this internal coherence is a primary reason for adoption of the metric system of units.

The SPE Metrication Subcommittee is endeavoring to provide SPE members with all information needed on the International System of Units and to provide tentative standards (compatible with SI coherence, decimal, and other principles) for the application of the SI system to SPE fields of interest. The tentative SPE standards are intended to reflect reasonable input from many sources, and we solicit your positive input with the assurance that all ideas will receive careful consideration.

Review of Selected Units

Certain of the quantities and units shown in Tables 2.2 and 2.3 may require clarification of usage (see also the notes preceding Tables 2.2 and 2.3).

Time

Although second(s) is the base time unit, any unit of time may be used — minute (min), hour (h), day (d), and year (a). Note that (a) is used as the abbreviation for year (annum) instead of (yr). The use of the minute as a time unit is discouraged because of abbreviation problems. It should be used only when another time unit is absolutely inappropriate.

Date and Time Designation

The Subcommittee proposes to recommend a standard date and time designation to the American Natl. Standards Inst., as shown below. This form already has been introduced in Canada.

76	— 10	— 03	— 16	: 24	: 14
year	month	day	hour	minute	second

(76-10-03-16:24:14)

The sequence is orderly and easy to remember; only needed portions of the sequence would be used — most documents would use the first three. No recommendation has been made for distinguishing the century, such as 1976 vs. 1876 vs. 2076.

Area

The hectare (ha) is allowable but its use should be confined to large areas that describe the areal extent of a por-

TABLE 2.1—NOMENCLATURE FOR TABLES 2.2 AND 2.3

Unit Symbol	Name	Quantity	Type of Unit
A	ampere	electric current	base SI unit
a	annum (year)	time	allowable (not official SI) unit
Bq	becquerel	activity (of radionuclides)	derived SI unit = 1/s
bar	bar	pressure	allowable (not official SI) unit, = 10^5 Pa
C	coulomb	quantity of electricity	derived SI unit, = 1 A·s
cd	candela	luminous intensity	base SI unit
°C	degree Celsius	temperature	derived SI unit = 1.0 K
°	degree	plane angle	allowable (not official SI) unit
d	day	time	allowable (not official SI) unit, = 24 hours
F	farad	electric capacitance	derived SI unit, = 1 A·s/V
Gy	gray	absorbed dose	derived SI unit, = J/kg
g	gram	mass	allowable (not official SI) unit, = 10^{-3} kg
H	henry	inductance	derived SI unit, = 1 V·s/A
h	hour	time	allowable (not official SI) unit, = 3.6×10^3 s
Hz	hertz	frequency	derived SI unit, = 1 cycle/s
ha	hectare	area	allowable (not official SI) unit, = 10^4 m^2
J	joule	work, energy	derived SI unit, = 1 N·m
K	kelvin	temperature	base SI unit
kg	kilogram	mass	base SI unit
kn	knot	velocity	allowable (not official SI) unit, = $5.144\,444 \times 10^{-1}$ m/s = 1.852 km/h
L	liter	volume	allowable (not official SI) unit, = 1 dm^3
lm	lumen	luminous flux	derived SI unit, = 1 cd·sr
lx	lux	illuminance	derived SI unit, = 1 lm/m^2
m	meter	length	base SI unit
min	minute	time	allowable (not official SI) unit
′	minute	plane angle	Allowable cartography (not official SI) unit
N	newton	force	derived SI unit, = 1 kg·m/s^2
naut. mile	U.S. nautical mile	length	allowable (not official SI) unit, = 1.852×10^3 m
Ω	ohm	electric resistance	derived SI unit, = 1 V/A
Pa	pascal	pressure	derived SI unit, = 1 N/m^2
rad	radian	plane angle	supplementary SI unit
S	siemens	electrical conductance	derived SI unit, = 1 A/V
s	second	time	base SI unit
″	second	plane angle	allowable cartography (not official SI) unit
sr	steradian	solid angle	supplementary SI unit
T	tesla	magnetic flux density	derived SI unit, = 1 Wb/m^2
t	tonne	mass	allowable (not official SI) unit, = 10^3 kg = 1 Mg
V	volt	electric potential	derived SI unit, = 1 W/A
W	watt	power	derived SI unit, = 1 J/s
Wb	weber	magnetic flux	derived SI unit, = 1 V·s

tion of the earth's crust (normally replacing the acre or section).

Volume

The liter is an allowable unit for small volumes only. It should be used for volumes not exceeding 100 L. Above this volume (or volume rate), cubic meters should be used. The only two prefixes allowed with the liter are "milli" and "micro."

In the U.S., the "-er" ending for meter and liter is official. The official symbol for the liter is "L." In other countries the symbol may be written as "ℓ" and spelled out with the "-re" ending (metre, litre). Since SPE is international, it is expected that members will use local conventions.

Notice that "API barrel" or simply "barrel" disappears as an allowable volume term.

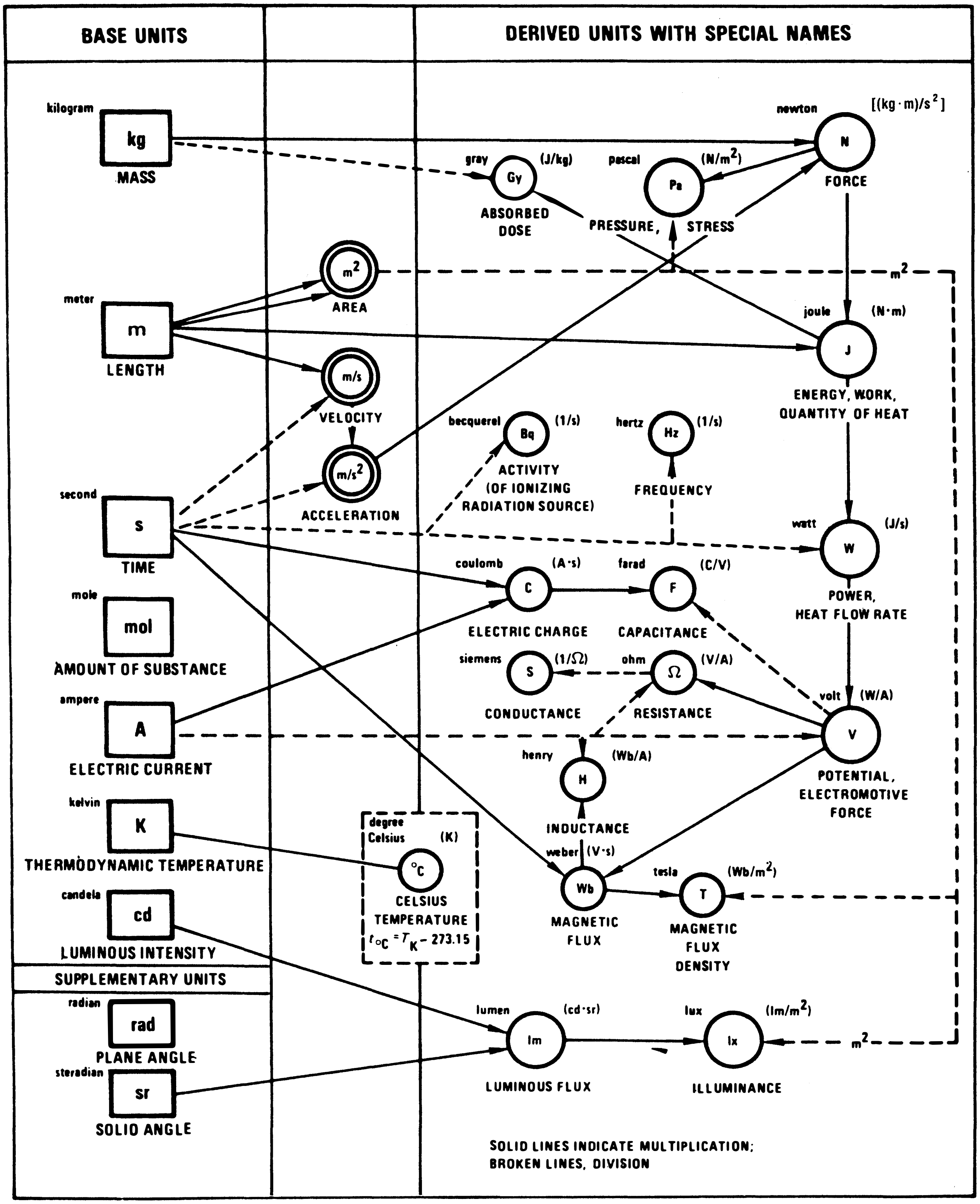

Fig. 2.1—Graphic Relationships of SI Units With Names.

Force

Any force term will use the newton (N). Derived units involving force also require the newton. The expression of force using a mass term (like the kilogram) is absolutely forbidden under these standards.

Mass

The kilogram is the base unit, but the gram, alone or with any approved prefix, is an acceptable SI unit.

For large mass quantities the metric ton (t) may be used. Some call this "tonne." However, this spelling sometimes has been used historically to denote a regular short ton (2,000 lbm). A metric ton is also a megagram (Mg). The terms metric ton or Mg are preferred in text references.

Energy and Work

The joule (J) is the fundamental energy unit; kilojoules (kJ) or megajoules (MJ) will be used most commonly. The calorie (large or small) is no longer an acceptable unit under these standards. The kilowatthour is acceptable for a transition period but eventually should be replaced by the megajoule.

Power

The term horsepower disappears as an allowable unit. The kilowatt (kW) or megawatt (MW) will be the multiples of the fundamental watt unit used most commonly.

Pressure

The fundamental pressure unit is the pascal (Pa) but the kilopascal (kPa) is the most convenient unit. The bar (100 kPa) is an allowable unit. The pressure term kg/cm^2 is not allowable under these standards.

Viscosity

The terms poise, centipoise, stokes, and centistokes are no longer used under these standards. They are replaced by the metric units shown in Table 2.2.

Temperature

Although it is permissible to use °C in text references, it is recommended that "K" be used in graphical and tabular summaries of data.

Density

The fundamental SI unit for density is kg/m^3. Use of this unit is encouraged. However, a unit like kg/L is permissible.

The traditional term "specific gravity" will not be used. It will be replaced by the term "relative density." API gravity disappears as a measure of relative density.

Relative Atomic Mass and Molecular Mass

The traditional terms "atomic weight" and "molecular weight" are replaced in the SI system of units by "relative atomic mass" and "relative molecular mass," respectively. See Table 1.6.

Unit Standards Under Discussion

There are some quantities for which the unit standards have not been clarified to the satisfaction of all parties and some controversy remains. These primary quantities are summarized below.

Permeability

The SPE-preferred permeability unit is the square micrometer (μm^2). One darcy (the traditional unit) equals 0.986 923 μm^2.*

The fundamental SI unit of permeability (in square meters) is defined as follows: "a permeability of one meter squared will permit a flow of 1 m^3/s of fluid of 1 Pa·s viscosity through an area of 1 m^2 under a pressure gradient of 1 Pa/m."

The traditional terms of "darcy" and "millidarcy" have been approved as preferred units of permeability. Note 11 of Table 2.2 shows the relationships between traditional and SI units and points out that the units of the darcy and the square micrometer can be considered equivalent when high accuracy is not needed or implied.

Standard Temperature

Some reference temperature is necessary to show certain properties of materials, such as density, volume, viscosity, energy level, etc. Historically, the petroleum industry almost universally has used 60°F (15.56°C) as this reference temperature, and metric systems have used 0°C, 20°C, and 25°C most commonly, depending on the data and the area of specialty.

API has opted for 15°C because it is close to 60°F ASME has used 20°C in some of its metric guides. The bulk of continental European data used for gas and oil correlations is at 0°C, although 15°C is used sometimes.

The SPE Subcommittee feels that the choice between 0°C and 15°C is arbitrary. Tentatively, a standard of 15°C has been adopted simply to conform to API standards. It may be desirable to have a flexible temperature standard for various applications.

Standard Pressure

To date, some groups have opted for a pressure reference of 101.325 kPa, which is the equivalent of one standard atmosphere. The Subcommittee considers this an unacceptable number. Its adoption possesses some short-term convenience advantages but condemns future generations to continual odd-number conversions to reflect the change of pressure on properties. It also violates the powers-of-10 aspect of the SI system, one of its primary advantages.

The current SPE standard is 100 kPa and should be used until further notice. It is our hope that reason will prevail and others will adopt this standard.

Gauge and Absolute Pressure

There is no provision for differentiating between gauge and absolute pressure, and actions by international bodies prohibit showing the difference by an addendum to the unit symbol. The Subcommittee recommends that gauge and absolute be shown using parentheses following p:

$p = 643$ kPa, $p(g) = 543$ kPa

[p is found from p(g) by adding actual barometric pressure. (100 kPa is suitable for most engineering calculations.)]

In custody transfer the standard pressure will be specified by contract. Unless there is a special reason not to do so, the standard pressure will be 100 kPa to preserve the "multiples of ten" principle of the metric system.

Standard pressure normally is defined and used as an absolute pressure. So, $p_{sc}=100$ kPa is proper notation. Absolute pressure is implied if no (g) is added to denote gauge pressure specifically.

Standard Volumes

Cubic meters at standard reference conditions must be equated to a term with the standard "*sc*" subscript. For example, for a gas production rate of 1 200 000 m^3/d, write

$q_{gsc}=1.2\times10^6$ m^3/d or 1.2 (E+06) m^3/d
read as "1.2 million cubic meters per day."

If the rate is 1200 cubic meters per day, write

$q_{gsc}=1.2\times10^3$ m^3/d.

For gas in place, one could write

$G_{sc}=11.0\times10^{12}$ m^3.

Notes for Table 2.2

1. The cubem (cubic mile) is used in the measurement of very large volumes, such as the content of a sedimentary basin.
2. In surveying, navigation, etc., angles no doubt will continue to be measured with instruments that read out in degrees, minutes, and seconds and need not be converted into radians. But for calculations involving rotational energy, radians are preferred.
3. The unit of a million years is used in geochronology. The mega-annum is the preferred SI unit, but many prefer simply to use mathematical notation (i.e., $\times10^6$).
4. This conversion factor is for an ideal gas.
5. Subsurface pressures can be measured in megapascals or as freshwater heads in meters. If the latter approach is adopted, the hydrostatic gradient becomes dimensionless.
6. Quantities listed under "Facility Throughput, Capacity" are to be used only for characterizing the size or capacity of a plant or piece of equipment. Quantities listed under "Flow Rate" are for use in design calculations.
7. This conversion factor is based on a density of 1.0 kg/dm^3.
8. Seismic velocities will be expressed in km/s.
9. The interval transit time unit is used in sonic logging work.
10. See discussion of "Energy, Torque, and Bending Moment," Part 1.
11. The permeability conversions shown in Table 2.2 are for the traditional definitions of darcy and millidarcy.

    In SI units, the square micrometer is the preferred unit of permeability in fluid flow through a porous medium, having the dimensions of viscosity times volume flow rate per unit area divided by pressure gradient, which simplifies to dimensions of length squared. (The *fundamental* SI unit is the square meter, defined by leaving out the factor of 10^{-12} in the equation below).

    A permeability of 1 μm^2 will permit a flow of 1 m^3/s of fluid of 1 Pa·s viscosity through an area of 1 m^2 under a pressure gradient of 10^{12} Pa/m (neglecting gravity effects):

$$\begin{aligned} 1\ \mu m^2 &= 10^{-12}\ \text{Pa}\cdot\text{s}\ [m^3/(s\cdot m^2)](m/\text{Pa}) \\ &= 10^{-12}\ \text{Pa}\cdot s(m/s)(m/\text{Pa}) \\ &= 10^{-12}\ m^2. \end{aligned}$$

    The range of values in petroleum work is best served by units of 10^{-3} μm^2. The traditional millidarcy (md) is an informal name for 10^{-3} μm^2, which may be used where high accuracy is not implied.

    For virtually all engineering purposes, the familiar darcy and millidarcy units may be taken equal to 1 μm^2 and 10^{-3} μm^2, respectively.
12. The ohm-meter is used in borehole geophysical devices.
13. As noted in Section 1, the mole is an amount of substance expressible in elementary entities as atoms, molecules, ions, electrons, and other particles or specified groups of such particles. Since the expression kilogram mole is inconsistent with other SI practices, we have used the abbreviation "kmol" to designate an amount of substance which contains as many kilograms (groups of molecules) as there are atoms in 0.012 kg of carbon 12 multiplied by the relative molecular mass of the substance involved. In effect, the "k" prefix is merely a convenient way to identify the type of entity and facilitate conversion from the traditional pound mole without violating SI conventions.

Notes for Table 2.3

1. The standard cubic foot (scf) and barrel (bbl) referred to are measured at 60°F and 14.696 psia; the cubic meter is measured at 15°C and 100 kPa (1 bar).
2. The kPa is the preferred SPE unit for pressure. But many are using the bar as a pressure measurement. The bar should be considered as a nonapproved name (or equivalent) for 100 kPa.
3. See discussion of "Torque, and Bending Moment," Part 1.

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		SPACE,** TIME				
Length	m	naut mile	km		1.852*	E+00
		mile	km		1.609 344*	E+00
		chain	m		2.011 68*	E+01
		link	m		2.011 68*	E−01
		fathom	m		1.828 8*	E+00
		m	m		1.0*	E+00
		yd	m		9.144*	E−01
		ft	m		3.048*	E−01
				cm	3.048*	E+01
		in.	mm		2.54*	E+01
				cm	2.54*	E+00
		cm	mm		1.0*	E+01
				cm	1.0*	E+00
		mm	mm		1.0*	E+00
		mil	μm		2.54*	E+01
		micron (μ)	μm		1.0*	E+00
Length/length	m/m	ft/mi	m/km		1.893 939	E−01
Length/volume	m/m^3	ft/U.S. gal	m/m^3		8.051 964	E+01
		ft/ft^3	m/m^3		1.076 391	E+01
		ft/bbl	m/m^3		1.917 134	E+00
Length/temperature	m/K	see "Temperature, Pressure, Vacuum"				
Area	m^2	sq mile	km^2		2.589 988	E+00
		section	km^2		2.589 988	E+00
				ha	2.589 988	E+02
		acre	m^2		4.046 856	E+03
				ha	4.046 856	E−01
		ha	m^2		1.0*	E+04
		sq yd	m^2		8.361 274	E−01
		sq ft	m^2		9.290 304*	E−02
				cm^2	9.290 304*	E+02
		sq in.	mm^2		6.451 6*	E+02
				cm^2	6.451 6*	E+00
		cm^2	mm^2		1.0*	E+02
				cm^2	1.0*	E+00
		mm^2	mm^2		1.0*	E+00
Area/volume	m^2/m^3	$ft^2/in.^3$	m^2/cm^3		5.699 291	E−03
Area/mass	m^2/kg	cm^2/g	m^2/kg		1.0*	E−01
			m^2/g		1.0*	E−04
Volume, capacity	m^3	cubem	km^3		4.168 182	E+00 (1)†
		acre-ft	m^3		1.233 489	E+03
				ha·m	1.233 489	E−01
		m^3	m^3		1.0*	E+00
		cu yd	m^3		7.645 549	E−01
		bbl (42 U.S. gal)	m^3		1.589 873	E−01
		cu ft	m^3		2.831 685	E−02
			dm^3	L	2.831 685	E+01
		U.K. gal	m^3		4.546 092	E−03
			dm^3	L	4.546 092	E+00
		U.S. gal	m^3		3.785 412	E−03
			dm^3	L	3.785 412	E+00
		liter	dm^3	L	1.0*	E+00
		U.K. qt	dm^3	L	1.136 523	E+00
		U.S. qt	dm^3	L	9.463 529	E−01
		U.S. pt	dm^3	L	4.731 765	E−01

*An asterisk indicates that the conversion factor is exact using the numbers shown; all subsequent numbers are zeros.

**Conversion factors for length, area, and volume (and related quantities) in Table 2.2 are based on the international foot. See Footnote 1 of Table 1.7, Part 1.

†See Notes 1 through 13 on Page 25.

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit SPE Preferred	Metric Unit Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		SPACE,** TIME				
Volume, capacity	m^3	U.K. fl oz	cm^3		2.841 308	E+01
		U.S. fl oz	cm^3		2.957 353	E+01
		cu in.	cm^3		1.638 706	E+01
		mL	cm^3		1.0*	E+00
Volume/length (linear displacement)	m^3/m	bbl/in.	m^3/m		6.259 342	E+00
		bbl/ft	m^3/m		5.216 119	E−01
		ft^3/ft	m^3/m		9.290 304*	E−02
		U.S. gal/ft	m^3/m		1.241 933	E−02
			dm^3/m	L/m	1.241 933	E+01
Volume/mass	m^3/kg	see "Density, Specific Volume, Concentration, Dosage"				
Plane angle	rad	rad	rad		1.0*	E+00
		deg (°)	rad		1.745 329	E−02 (2)
				°	1.0*	E+00
		min (′)	rad		2.908 882	E−04 (2)
				′	1.0*	E+00
		sec (″)	rad		4.848 137	E−06 (2)
				″	1.0*	E+00
Solid angle	sr	sr	sr		1.0*	E+00
Time	s	million years (MY)	Ma		1.0*	E+00 (3)
		yr	a		1.0*	E+00
		wk	d		7.0*	E+00
		d	d		1.0*	E+00
		hr	h		1.0*	E+00
				min	6.0*	E+01
		min	s		6.0*	E+01
				h	1.666 667	E−02
				min	1.0*	E+00
		s	s		1.0*	E+00
		millimicrosecond	ns		1.0*	E+00
		MASS, AMOUNT OF SUBSTANCE				
Mass	kg	U.K. ton (long ton)	Mg	t	1.016 047	E+00
		U.S. ton (short ton)	Mg	t	9.071 847	E−01
		U.K. ton	kg		5.080 235	E+01
		U.S. cwt	kg		4.535 924	E+01
		kg	kg		1.0*	E+00
		lbm	kg		4.535 924	E−01
		oz (troy)	g		3.110 348	E+01
		oz (av)	g		2.834 952	E+01
		g	g		1.0*	E+00
		grain	mg		6.479 891	E+01
		mg	mg		1.0*	E+00
		g	g		1.0*	E+00
Mass/length	kg/m	see "Mechanics"				
Mass/area	kg/m^2	see "Mechanics"				
Mass/volume	kg/m^3	see "Density, Specific Volume, Concentration, Dosage"				
Mass/mass	kg/kg	see "Density, Specific Volume, Concentration, Dosage"				
Amount of substance	mol	lbm mol	kmol		4.535 924	E−01
		g mol	kmol		1.0*	E−03
		std m^3 (0°C, 1 atm)	kmol		4.461 58	E−02 (4,13)
		std m^3 (15°C, 1 atm)	kmol		4.229 32	E−02 (4,13)
		std ft^3 (60°F, 1 atm)	kmol		1.195 3	E−03 (4,13)

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
CALORIFIC VALUE, HEAT, ENTROPY, HEAT CAPACITY						
Calorific value (mass basis)	J/kg	Btu/lbm	MJ/kg		2.326	E−03
			kJ/kg	J/g	2.326	E+00
				(kW·h)/kg	6.461 112	E−04
		cal/g	kJ/kg	J/g	4.184*	E+00
		cal/lbm	J/kg		9.224 141	E+00
Calorific value (mole basis)	J/mol	kcal/g mol	kJ/kmol		4.184*	C+03[13]
		Btu/lbm mol	MJ/kmol		2.326	E−03[13]
			kJ/kmol		2.326	E+00[13]
Calorific value (volume basis — solids and liquids)	J/m^3	therm/U.K. gal	MJ/m^3	kJ/dm^3	2.320 80	E+04
			kJ/m^3		2.320 80	E+07
				(kW·h)/dm^3	6.446 660	E+00
		Btu/U.S. gal	MJ/m^3	kJ/dm^3	2.787 163	E−01
			kJ/m^3		2.787 163	E+02
				(kW·h)/m^3	7.742 119	E−02
		Btu/U.K. gal	MJ/m^3	kJ/dm^3	2.320 8	E−01
			kJ/m^3		2.320 8	E+02
				(kW·h)/m^3	6.446 660	E−02
		Btu/ft^3	MJ/m^3	kJ/dm^3	3.725 895	E−02
			kJ/m^3		3.725 895	E+01
				(kW·h)/m^3	1.034 971	E−02
		kcal/m^3	MJ/m^3	kJ/dm^3	4.184*	E−03
			kJ/m^3		4.184*	E+00
		cal/mL	MJ/m^3		4.184*	E+00
		ft-lbf/U.S. gal	kJ/m^3		3.581 692	E−01
Calorific value (volume basis — gases)	J/m^3	cal/mL	kJ/m^3	J/dm^3	4.184*	E+03
		kcal/m^3	kJ/m^3	J/dm^3	4.184*	E+00
		Btu/ft^3	kJ/m^3	J/dm^3	3.725 895	E+01
				(kW·h)/m^3	1.034 971	E−02
Specific entropy	J/kg·K	Btu/(lbm-°R)	kJ/(kg·K)	J(g·K)	4.186 8*	E+00
		cal/(g-°K)	kJ/(kg·K)	J(g·K)	4.184*	E+00
		kcal/(kg-°C)	kJ/(kg·K)	J(g·K)	4.184*	E+00
Specific heat capacity (mass basis)	J/kg·K	kW-hr/(kg-°C)	kJ/(kg·K)	J(g·K)	3.6*	E+03
		Btu/(lbm-°F)	kJ/(kg·K)	J(g·K)	4.186 8*	E+00
		kcal/(kg-°C)	kJ/(kg·K)	J(g·K)	4.184*	E+00
Molar heat capacity	J/mol·K	Btu/(lbm mol-°F)	kJ/(kmol·K)		4.186 8*	E+00[13]
		cal/(g mol-°C)	kJ/(kmol·K)		4.184*	E−00[13]
TEMPERATURE, PRESSURE, VACUUM						
Temperature (absolute)	K	°R	K		5/9	
		°K	K		1.0*	E+00
Temperature (traditional)	K	°F	°C		(°F−32)/1.8	
		°C	°C		1.0*	E+00
Temperature (difference)	K	°F	K	°C	5/9	E+00
		°C	K	°C	1.0*	E+00
Temperature/length (geothermal gradient)	K/m	°F/100 ft	mK/m		1.822 689	E+01
Length/temperature (geothermal step)	m/K	ft/°F	m/K		5.486 4*	E−01
Pressure	Pa	atm (760mm Hg at 0°C or 14.696 (lbf/in.^{2}))	MPa		1.013 25*	E−01
			kPa		1.013 25*	E+02
				bar	1.013 25*	E+00
		bar	MPa		1.0*	E−01
			kPa		1.0*	E+02
				bar	1.0*	E+00
		at (technical atm., kgf/cm^2)	MPa		9.806 65*	E−02
			kPa		9.806 65*	E+01
				bar	9.806 65*	E−01

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
TEMPERATURE, PRESSURE, VACUUM						
Pressure	Pa	lbf/in.^{2} (psi)	MPa		6.894 757	E−03
			kPa		6.894 757	E+00
				bar	6.894 757	E−02
		in. Hg (32°F)	kPa		3.386 38	E+00
		in. Hg (60°F)	kPa		3.376 85	E+00
		in. H_2O (39.2°F)	kPa		2.490 82	E−01
		in. H_2O (60°F)	kPa		2.488 4	E−01
		mm Hg (0°C) = torr	kPa		1.333 224	E−01
		cm H_2O (4°C)	kPa		9.806 38	E−02
		lbf/ft^2 (psf)	kPa		4.788 026	E−02
		μm Hg (0°C)	Pa		1.333 224	E−01
		μbar	Pa		1.0*	E−01
		dyne/cm^2	Pa		1.0*	E−01
Vacuum, draft	Pa	in. Hg (60°F)	kPa		3.376 85	E+00
		in. H_2O (39.2°F)	kPa		2.490 82	E−01
		in. H_2O (60°F)	kPa		2.488 4	E−01
		mm Hg (0°C) = torr	kPa		1.333 224	E−01
		cm H_2O (4°C)	kPa		9.806 38	E−02
Liquid head	m	ft	m		3.048*	E−01
		in.	mm		2.54*	E+01
				cm	2.54*	E+00
Pressure drop/length	Pa/m	psi/ft	kPa/m		2.262 059	E+01
		psi/100 ft	kPa/m		2.262 059	E−01[(5)]
DENSITY, SPECIFIC VOLUME, CONCENTRATION, DOSAGE						
Density (gases)	kg/m^3	lbm/ft^3	kg/m^3		1.601 846	E+01
			g/m^3		1.601 846	E+04
Density (liquids)	kg/m^3	lbm/U.S. gal	kg/m^3		1.198 264	E+02
				g/cm^3	1.198 264	E−01
		lbm/U.K. gal	kg/m^3		9.977 633	E+01
				kg/dm^3	9.977 633	E−02
		lbm/ft^3	kg/m^3		1.601 846	E+01
				g/cm^3	1.601 846	E−02
		g/cm^3	kg/m^3		1.0*	E+03
				kg/dm^3	1.0*	E+00
		°API	g/cm^3		141.5/(131.5+°API)	
Density (solids)	kg/m^3	lbm/ft^3	kg/m^3		1.601 846	E+01
Specific volume (gases)	m^3/kg	ft^3/lbm	m^3/kg		6.242 796	E−02
			m^3/g		6.242 796	E−05
Specific volume (liquids)	m^3/kg	ft^3/lbm	dm^3/kg		6.242 796	E+01
		U.K. gal/lbm	dm^3/kg	cm^3/g	1.002 242	E+01
		U.S. gal/lbm	dm^3/kg	cm^3/g	8.345 404	E+00
Specific volume (mole basis)	m^3/mol	L/g mol	m^3/kmol		1.0*	E+00[13]
		ft^3/lbm mol	m^3/kmol		6.242 796	E−02[13]
Specific volume (clay yield)	m^3/kg	bbl/U.S. ton	m^3/t		1.752 535	E−01
		bbl/U.K. ton	m^3/t		1.564 763	E−01
Yield (shale distillation)	m^3/kg	bbl/U.S. ton	dm^3/t	L/t	1.752 535	E+02
		bbl/U.K. ton	dm^3/t	L/t	1.564 763	E+02
		U.S. gal/U.S. ton	dm^3/t	L/t	4.172 702	E+00
		U.S. gal/U.K. ton	dm^3/t	L/t	3.725 627	E+00
Concentration (mass/mass)	kg/kg	wt %	kg/kg		1.0*	E−02
			g/kg		1.0*	E+01
		wt ppm	mg/kg		1.0*	E+00
Concentration (mass/volume)	kg/m^3	lbm/bbl	kg/m^3	g/dm^3	2.853 010	E+00
		g/U.S. gal	kg/m^3		2.641 720	E−01
		g/U.K. gal	kg/m^3	g/L	2.199 692	E−01

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
DENSITY, SPECIFIC VOLUME, CONCENTRATION, DOSAGE						
Concentration (mass/volume)	kg/m^3	lbm/1000 U.S. gal	g/m^3	mg/dm^3	1.198 264	E+02
		lbm/1000 U.K. gal	g/m^3	mg/dm^3	9.977 633	E+01
		grains/U.S. gal	g/m^3	mg/dm^3	1.711 806	E+01
		$grains/ft^3$	mg/m^3		2.288 352	E+03
		lbm/1000 bbl	g/m^3	mg/dm^3	2.853 010	E+00
		mg/U.S. gal	g/m^3	mg/dm^3	2.641 720	E−01
		grains/100 ft^3	mg/m^3		2.288 352	E+01
Concentration (volume/volume)	m^3/m^3	bbl/bbl	m^3/m^3		1.0*	E+00
		ft^3/ft^3	m^3/m^3		1.0*	E+00
		bbl/acre·ft	m^3/m^3		1.288 923	E−04
				$m^3/ha{\cdot}m$	1.288 923	E+00
		vol %	m^3/m^3		1.0*	E−02
		U.K. gal/ft^3	dm^3/m^3	L/m^3	1.605 437	E+02
		U.S. gal/ft^3	dm^3/m^3	L/m^3	1.336 806	E+02
		mL/U.S. gal	dm^3/m^3	L/m^3	2.641 720	E−01
		mL/U.K. gal	dm^3/m^3	L/m^3	2.199 692	E−01
		vol ppm	cm^3/m^3		1.0*	E+00
			dm^3/m^3	L/m^3	1.0*	E−03
		U.K. gal/1000 bbl	cm^3/m^3		2.859 406	E+01
		U.S. gal/1000 bbl	cm^3/m^3		2.380 952	E+01
		U.K. pt/1000 bbl	cm^3/m^3		3.574 253	E+00
Concentration (mole/volume)	mol/m^3	lbm mol/U.S. gal	$kmol/m^3$		1.198 264	E+02
		lbm mol/U.K. gal	$kmol/m^3$		9.977 633	E+01
		lbm mol/ft^3	$kmol/m^3$		1.601 846	E+01
		std ft^3 (60°F, 1 atm)/bbl	$kmol/m^3$		7.518 18	E−03
Concentration (volume/mole)	m^3/mol	U.S. gal/1000 std ft^3 (60°F/60°F)	$dm^3/kmol$	L/kmol	3.166 93	E+00
		bbl/million std ft^3 (60°F/60°F)	$dm^3/kmol$	L/kmol	1.330 11	E−01
FACILITY THROUGHPUT, CAPACITY						
Throughput (mass basis)	kg/s	million lbm/yr	t/a	Mg/a	4.535 924	E+02
		U.K. ton/yr	t/a	Mg/a	1.016 047	E+00
		U.S. ton/yr	t/a	Mg/a	9.071 847	E−01
		U.K. ton/D	t/d	Mg/d	1.016 047	E+00
				t/h, Mg/h	4.233 529	E−02
		U.S. ton/D	t/d		9.071 847	E−01
				t/h, Mg/h	3.779 936	E−02
		U.K. ton/hr	t/h	Mg/h	1.016 047	E+00
		U.S. ton/hr	t/h	Mg/h	9.071 847	E−01
		lbm/hr	kg/h		4.535 924	E−01
Throughput (volume basis)	m^3/s	bbl/D	t/a		5.803 036	E+01 (7)
				m^3/d	1.589 873	E−01
			m^3/h		6.624 471	E−03
		ft^3/D	m^3/h		1.179 869	E−03
				m^3/d	2.831 685	E−02
		bbl/hr	m^3/h		1.589 873	E−01
		ft^3/h	m^3/h		2.831 685	E−02
		U.K. gal/hr	m^3/h		4.546 092	E−03
				L/s	1.262 803	E−03
		U.S. gal/hr	m^3/h		3.785 412	E−03
				L/s	1.051 503	E−03
		U.K. gal/min	m^3/h		2.727 655	E−01
				L/s	7.576 819	E−02
		U.S. gal/min	m^3/h		2.271 247	E−01
				L/s	6.309 020	E−02

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		FACILITY THROUGHPUT, CAPACITY				[6]
Throughput (mole basis)	mol/s	lbm mol/hr	kmol/h		4.535 924	E−01
				kmol/s	1.259 979	E−04
		FLOW RATE				[6]
Pipeline capacity	m^3/m	bbl/mile	m^3/km		9.879 013	E−02
Flow rate (mass basis)	kg/s	U.K. ton/min	kg/s		1.693 412	E+01
		U.S. ton/min	kg/s		1.511 974	E+01
		U.K. ton/hr	kg/s		2.822 353	E−01
		U.S. ton/hr	kg/s		2.519 958	E−01
		U.K. ton/D	kg/s		1.175 980	E−02
		U.S. ton/D	kg/s		1.049 982	E−02
		million lbm/yr	kg/s		5.249 912	E+00
		U.K. ton/yr	kg/s		3.221 864	E−05
		U.S. ton/yr	kg/s		2.876 664	E−05
		lbm/s	kg/s		4.535 924	E−01
		lbm/min	kg/s		7.559 873	E−03
		lbm/hr	kg/s		1.259 979	E−04
Flow rate (volume basis)	m^3/s	bbl/D	m^3/d		1.589 873	E−01
				L/s	1.840 131	E−03
		ft^3/D	m^3/d		2.831 685	E−02
				L/s	3.277 413	E−04
		bbl/hr	m^3/s		4.416 314	E−05
				L/s	4.416 314	E−02
		ft^3/hr	m^3/s		7.865 791	E−06
				L/s	7.865 791	E−03
		U.K. gal/hr	dm^3/s	L/s	1.262 803	E−03
		U.S. gal/hr	dm^3/s	L/s	1.051 503	E−03
		U.K. gal/min	dm^3/s	L/s	7.576 820	E−02
		U.S. gal/min	dm^3/s	L/s	6.309 020	E−02
		ft^3/min	dm^3/s	L/s	4.719 474	E−01
		ft^3/s	dm^3/s	L/s	2.831 685	E+01
Flow rate (mole basis)	mol/s	lbm mol/s	kmol/s		4.535 924	E−01[13]
		lbm mol/hr	kmol/s		1.259 979	E−04[13]
		million scf/D	kmol/s		1.383 449	E−02[13]
Flow rate/length (mass basis)	kg/s·m	lbm/(s-ft)	kg/(s·m)		1.488 164	E+00
		lbm/(hr-ft)	kg/(s·m)		4.133 789	E−04
Flow rate/length (volume basis)	m^2/s	U.K. gal/(min-ft)	m^2/s	m^3/(s·m)	2.485 833	E−04
		U.S. gal/(min-ft)	m^2/s	m^3/(s·m)	2.069 888	E−04
		U.K. gal/(hr-in.)	m^2/s	m^3/(s·m)	4.971 667	E−05
		U.S. gal/(hr-in.)	m^2/s	m^3/(s·m)	4.139 776	E−05
		U.K. gal/(hr-ft)	m^2/s	m^3/(s·m)	4.143 055	E−06
		U.S. gal/(hr-ft)	m^2/s	m^3/(s·m)	3.449 814	E−06
Flow rate/area (mass basis)	kg/s·m^2	lbm/(s-ft^2)	kg/s·m^2		4.882 428	E+00
		lbm/(hr-ft^2)	kg/s·m^2		1.356 230	E−03
Flow rate/area (volume basis)	m/s	ft^3/(s-ft^2)	m/s	m^3(s·m^2)	3.048*	E−01
		ft^3/(min-ft^2)	m/s	m^3/(s·m^2)	5.08*	E−03
		U.K. gal/(hr-$in.^2$)	m/s	m^3/(s·m^2)	1.957 349	E−03
		U.S. gal/(hr-$in.^2$)	m/s	m^3/(s·m^2)	1.629 833	E−03
		U.K. gal/(min-ft^2)	m/s	m^3/(s·m^2)	8.155 621	E−04
		U.S. gal/(min-ft^2)	m/s	m^3/(s·m^2)	6.790 972	E−04
		U.K. gal/(hr-ft^2)	m/s	m^3/(s·m^2)	1.359 270	E−05
		U.S. gal/(hr-ft^2)	m/s	m^3/(s·m^2)	1.131 829	E−05
Flow rate/ pressure drop (productivity index)	m^3/s·Pa	bbl/(D-psi)	m^3/(d·kPa)		2.305 916	E−02

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit SPE Preferred	Metric Unit Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		ENERGY, WORK, POWER				
Energy, work	J	quad	MJ		1.055 056	E+12
			TJ		1.055 056	E+06
			EJ		1.055 056	E+00
				MW·h	2.930 711	E+08
				GW·h	2.930 711	E+05
				TW·h	2.930 711	E+02
		therm	MJ		1.055 056	E+02
			kJ		1.055 056	E+05
				kW·h	2.930 711	E+01
		U.S. tonf-mile	MJ		1.431 744	E+01
		hp-hr	MJ		2.684 520	E+00
			kJ		2.684 520	E+03
				kW·h	7.456 999	E−01
		ch-hr or CV-hr	MJ		2.647 796	E+00
			Kj		2.647 796	E+03
				kW·h	7.354 99	E−01
		kW-hr	MJ		3.6*	E+00
			kJ		3.6*	E+03
		Chu	kJ		1.899 101	E+00
				kW·h	5.275 280	E−04
		Btu	kJ		1.055 056	E+00
				kW·h	2.930 711	E−04
		kcal	kJ		4.184*	E+00
		cal	kJ		4.184*	E−03
		ft-lbf	kJ		1.355 818	E−03
		lbf-ft	kJ		1.355 818	E−03
		J	kJ		1.0*	E−03
		lbf-ft²/s²	kJ		4.214 011	E−05
		erg	J		1.0*	E−07
Impact energy	J	kgf-m	J		9.806 650*	E+00
		lbf-ft	J		1.355 818	E+00
Work/length	J/m	U.S. tonf-mile/ft	MJ/m		4.697 322	E+01
Surface energy	J/m²	erg/cm²	mJ/m²		1.0*	E+00
Specific impact energy	J/m²	kgf·m/cm²	J/cm²		9.806 650*	E−00
		lbf·ft/in.²	J/cm²		2.101 522	E−01
Power	W	quad/yr	MJ/a		1.055 056	E+12
			TJ/a		1.055 056	E+06
			EJ/a		1.055 056	E+00
		erg/a	TW		3.170 979	E−27
			GW		3.170 979	E−24
		million Btu/hr	MW		2.930 711	E−01
		ton of refrigeration	kW		3.516 853	E+00
		Btu/s	kW		1.055 056	E+00
		kW	kW		1.0*	E+00
		hydraulic horse-power — hhp	kW		7.460 43	E−01
		hp (electric)	kW		7.46*	E−01
		hp (550 ft-lbf/s)	kW		7.456 999	E−01
		ch or CV	kW		7.354 99	E−01
		Btu/min	kW		1.758 427	E−02
		ft·lbf/s	kW		1.355 818	E−03
		kcal/hr	W		1.162 222	E+00
		Btu/hr	W		2.930 711	E−01
		ft·lbf/min	W		2.259 697	E−02
Power/area	W/m²	Btu/s·ft²	kW/m²		1.135 653	E+01
		cal/hr·cm²	kW/m²		1.162 222	E−02
		Btu/hr·ft²	kW/m²		3.154 591	E−03

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit SPE Preferred	Metric Unit Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		ENERGY, WORK, POWER				
Heat flow unit — hfu (geothermics)		μcal/s·cm²	mW/m²		4.184*	E+01
Heat release rate, mixing power	W/m³	hp/ft³	kW/m³		2.633 414	E+01
		cal/(hr·cm³)	kW/m³		1.162 222	E+00
		Btu/(s·ft³)	kW/m³		3.725 895	E+01
		Btu/(hr·ft³)	kW/m³		1.034 971	E−02
Heat generation unit — hgu (radioactive rocks)		cal/(s·cm³)	μW/m³		4.184*	E+12
Cooling duty (machinery)	W/W	Btu/(bhp-hr)	W/kW		3.930 148	E−01
Specific fuel consumption (mass basis)	kg/J	lbm/(hp-hr)	mg/J	kg/MJ	1.689 659	E−01
				kg/(kW·h)	6.082 774	E−01
Specific fuel consumption (volume basis)	m³/J	m³/(kW-hr)	dm³/MJ	mm³/J	2.777 778	E+02
				dm³/(kW·h)	1.0*	E+03
		U.S. gal/(hp-hr)	dm³/MJ	mm³/J	1.410 089	E+00
				dm³/(kW·h)	5.076 321	E+00
		U.K. pt/(hp-hr)	dm³/MJ	mm³/J	2.116 809	E−01
				dm³/(kW·h)	7.620 512	E−01
Fuel consumption (automotive)	m³/m	U.K. gal/mile	dm³/100 km	L/100 km	2.824 811	E+02
		U.S. gal/mile	dm³/100 km	L/100 km	2.352 146	E+02
		mile/U.S. gal	km/dm³	km/L	4.251 437	E−01
		mile/U.K. gal	km/dm³	km/L	3.540 060	E−01
		MECHANICS				
Velocity (linear), speed	m/s	knot	km/h		1.852*	E+00
		mile/hr	km/h		1.609 344*	E+00
		m/s	m/s		1.0*	E+00
		ft/s	m/s		3.048*	E−01
				cm/s	3.048*	E+01
				m/ms	3.048*	E−04(8)
		ft/min	m/s		5.08*	E−03
				cm/s	5.08*	E−01
		ft/hr	mm/s		8.466 667	E−02
				cm/s	8.466 667	E−03
		ft/D	mm/s		3.527 778	E−03
				m/d	3.048*	E−01
		in./s	mm/s		2.54*	E+01
				cm/s	2.54*	E+00
		in./min	mm/s		4.233 333	E−01
				cm/s	4.233 333	E−02
Velocity (angular)	rad/s	rev/min	rad/s		1.047 198	E−01
		rev/s	rad/s		6.283 185	E+00
		degree/min	rad/s		2.908 882	E−04
Interval transit time	s/m	s/ft	s/m	μs/m	3.280 840	E+00(9)
Corrosion rate	m/s	in./yr (ipy)	mm/a		2.54*	E+01
		mil/yr	mm/a		2.54*	E−02
Rotational frequency	rev/s	rev/s	rev/s		1.0*	E+00
		rev/min	rev/s		1.666 667	E−02
		rev/min	rad/s		1.047 198	E−01
Acceleration (linear)	m/s²	ft/s²	m/s²		3.048*	E−01
				cm/s²	3.048*	E+01
		gal(cm/s²)	m/s²		1.0*	E−02
Acceleration (rotational)	rad/s²	rad/s²	rad/s²		1.0*	E+00
		rpm/s	rad/s²		1.047 198	E−01
Momentum	kg·m/s	lbm·ft/s	kg·m/s		1.382 550	E−01

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		MECHANICS				
Force	N	U.K. tonf	kN		9.964 016	E+00
		U.S. tonf	kN		8.896 443	E+00
		kgf (kp)	N		9.806 650*	E+00
		lbf	N		4.448 222	E+00
		N	N		1.0*	E+00
		pdl	mN		1.382 550	E+02
		dyne	mN		1.0*	E−02
Bending moment, torque	N·m	U.S. tonf-ft	kN·m		2.711 636	E+00(10)
		kgf-m	N·m		9.806 650*	E+00(10)
		lbf-ft	N·m		1.355 818	E+00(10)
		lbf-in.	N·m		1.129 848	E−01(10)
		pdl-ft	N·m		4.214 011	E−02(10)
Bending moment/ length	N·m/m	(lbf-ft)/in.	(N·m)/m		5.337 866	E+01(10)
		(kgf-m)/m	(N·m)/m		9.806 650*	E+00(10)
		(lbf-in.)/in.	(N·m)/m		4.448 222	E+00(10)
Elastic moduli (Young's, Shear bulk)	Pa	lbf/in.^{2}	GPa		6.894 757	E−06
Moment of inertia	kg·m^2	lbm-ft^2	kg·m^2		4.214 011	E−02
Moment of section	m^4	in.^{4}	cm^4		4.162 314	E+01
Section modulus	m^3	cu in.	cm^3		1.638 706	E+01
		cu ft	cm^3		1.638 706	E+04
				mm^3	2.831 685	E+04
				m^3	2.831 685	E−02
Stress	Pa	U.S. tonf/in.^{2}	MPa	N/mm^2	1.378 951	E+01
		kgf/mm^2	MPa	N/mm^2	9.806 650*	E+00
		U.S. tonf/ft^2	MPa	N/mm^2	9.576 052	E−02
		lbf/in.^{2} (psi)	MPa	N/mm^2	6.894 757	E−03
		lbf/ft^2 (psf)	kPa		4.788 026	E−02
		dyne/cm^2	Pa		1.0*	E−01
Yield point, gel strength (drilling fluid)		lbf/100 ft^2	Pa		4.788 026	E−01
Mass/length	kg/m	lbm/ft	kg/m		1.488 164	E+00
Mass/area structural loading, bearing capacity (mass basis)	kg/m^2	U.S. ton/ft^2	Mg/m^2		9.764 855	E+00
		lbm/ft^2	kg/m^2		4.882 428	E+00
Coefficient of thermal expansion	m/(m·K)	in./(in.-°F)	mm/(mm·K)		5.555 556	E−01
		TRANSPORT PROPERTIES				
Diffusivity	m^2/s	ft^2/s	mm^2/s		9.290 304*	E+04
		cm^2/s	mm^2/s		1.0*	E+02
		ft^2/hr	mm^2/s		2.580 64*	E+01
Thermal resistance	(k·m^2)/W	(°C-m^2·hr)/kcal	(K·m^2)/kW		8.604 208	E+02
		(°F-ft^2 hr)/Btu	(K·m^2)/kW		1.761 102	E+02
Heat flux	W/m^2	Btu/(hr-ft^2)	kW/m^2		3.154 591	E−03
Thermal conductivity	W/(m·K)	(cal/s-cm^2-°C)/cm	W/(m·K)		4.184*	E+02
		Btu/(hr-ft^2-°F/ft)	W/(m·K)		1.730 735	E+00
				kJ·m/(h·m^2·K)	6.230 646	E+00
		kcal/(hr-m^2-°C/m)	W/(m·K)		1.162 222	E+00
		Btu/(hr-ft^2-°F/in.)	W/(m·K)		1.442 279	E−01
		cal/(hr-cm^2-°C/cm)	W/(m·K)		1.162 222	E−01

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		TRANSPORT PROPERTIES				
Heat transfer coefficient	W/(m^2·K)	cal/(s-cm^2-°C)	kW/(m^2·K)		4.184*	E+01
		Btu/(s-ft^2-°F)	kW/(m^2·K)		2.044 175	E+01
		cal/(hr-cm^2-°C)	kW/(m^2·K)		1.162 222	E−02
		Btu/(hr-ft^2-°F)	kW/(m^2·K)		5.678 263	E−03
				kJ/(h·m^2·K)	2.044 175	E+01
		Btu/(hr-ft^2-°R)	kW/(m^2·K)		5.678 263	E−03
		kcal/(hr-m^2-°C)	kW/(m^2·K)		1.162 222	E−03
Volumetric heat transfer coefficient	W/(m^3·K)	Btu/(s-ft^3-°F)	kW/(m^3·K)		6.706 611	E+01
		Btu/(hr-ft^3-°F)	kW/(m^3·K)		1.862 947	E−02
Surface tension	N/m	dyne/cm	mN/m		1.0*	E+00
Viscosity (dynamic)	Pa·s	(lbf-s)/$in.^2$	Pa·s	(N·s)/m^2	6.894 757	E+03
		(lbf-s)/ft^2	Pa·s	(N·s)/m^2	4.788 026	E+01
		(kgf-s)/m^2	Pa·s	(N·s)/m^2	9.806 650*	E+00
		lbm/(ft-s)	Pa·s	(N·s)/m^2	1.488 164	E+00
		(dyne-s)/cm^2	Pa·s	(N·s)/m^2	1.0*	E−01
		cp	Pa·s	(N·s)/m^2	1.0*	E−03
		lbm/(ft·hr)	Pa·s	(N·s)/m^2	4.133 789	E−04
Viscosity (kinematic)	m^2/s	ft^2/s	mm^2/s		9.290 304*	E+04
		$in.^2$/s	mm^2/s		6.451 6*	E+02
		m^2/hr	mm^2/s		2.777 778	E+02
		cm^2/s	mm^2/s		1.0*	E+02
		ft^2/hr	mm^2/s		2.580 64*	E+01
		cSt	mm^2/s		1.0*	E+00
Permeability	m^2	darcy	μm^2		9.869 233	E−01[11]
		millidarcy	μm^2		9.869 233	E−04[11]
				10^{-3} μm^2	9.869 233	E−01[11]
		ELECTRICITY, MAGNETISM				
Admittance	S	S	S		1.0*	E+00
Capacitance	F	μF	μF		1.0*	E+00
Capacity, storage battery	C	A-hr	kC		3.6*	E+00
Charge density	C/m^3	C/mm^3	C/mm^3		1.0*	E+00
Conductance	S	S	S		1.0*	E+00
		℧ (mho)	S		1.0*	E+00
Conductivity	S/m	S/m	S/m		1.0*	E+00
		℧/m	S/m		1.0*	E+00
		m℧/m	mS/m		1.0*	E+00
Current density	A/m^2	A/mm^2	A/mm^2		1.0*	E+00
Displacement	C/m^2	C/cm^2	C/cm^2		1.0*	E+00
Electric charge	C	C	C		1.0*	E+00
Electric current	A	A	A		1.0*	E+00
Electric dipole moment	C·m	C·m	C·m		1.0*	E+00
Electric field strength	V/m	V/m	V/m		1.0*	E+00
Electric flux	C	C	C		1.0*	E+00
Electric polarization	C/m^2	C/cm^2	C/cm^2		1.0*	E+00
Electric potential	V	V	V		1.0*	E+00
		mV	mV		1.0*	E+00
Electromagnetic moment	A·m^2	A·m^2	A·m^2		1.0*	E+00
Electromotive force	V	V	V		1.0*	E+00
Flux of displacement	C	C	C		1.0*	E+00

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit SPE Preferred	Metric Unit Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		ELECTRICITY, MAGNETISM				
Frequency	Hz	cycles/s	Hz		1.0*	E+00
Impedance	Ω	Ω	Ω		1.0*	E+00
Interval transit time	s/m	μs/ft	μs/m		3.280 840	E+00
Linear current density	A/m	A/mm	A/mm		1.0*	E+00
Magnetic dipole moment	Wb·m	Wb·m	Wb·m		1.0*	E+00
Magnetic field strength	A/m	A/mm	A/mm		1.0*	E+00
		oersted	A/m		7.957 747	E+01
		gamma	A/m		7.957 747	E−04
Magnetic flux	Wb	mWb	mWb		1.0*	E+00
Magnetic flux density	T	mT	mT		1.0*	E+00
		gauss	T		1.0*	E−04
Magnetic induction	T	mT	mT		1.0*	E+00
Magnetic moment	A·m^2	A·m^2	A·m^2		1.0*	E+00
Magnetic polarization	T	mT	mT		1.0*	E+00
Magnetic potential difference	A	A	A		1.0*	E+00
Magnetic vector potential	Wb/m	Wb/mm	Wb/mm		1	
Magnetization	A/m	A/mm	A/mm		1	
Modulus of admittance	S	S	S		1	
Modulus of impedance	Ω	Ω	Ω		1	
Mutual inductance	H	H	H		1	
Permeability	H/m	μH/m	μH/m		1	
Permeance	H	H	H		1	
Permittivity	F/m	μF/m	μF/m		1	
Potential difference	V	V	V		1	
Quantity of electricity	C	C	C		1	
Reactance	Ω	Ω	Ω		1	
Reluctance	H^{-1}	H^{-1}	H^{-1}		1	
Resistance	Ω	Ω	Ω		1	
Resistivity	Ω·m	Ω·cm	Ω·cm		1	
		Ω·m	Ω·m		1	(12)
Self inductance	H	mH	mH		1	
Surface density of charge	C/m^2	mC/m^2	mC/m^2		1	
Susceptance	S	S	S		1	
Volume density of charge	C/m^3	C/mm^3	C/mm^3		1	
		ACOUSTICS, LIGHT, RADIATION				
Absorbed dose	Gy	rad	Gy		1.0*	E−02
Acoustical energy	J	J	J		1	
Acoustical intensity	W/m^2	W/cm^2	W/m^2		1.0*	E+04
Acoustical power	W	W	W		1	
Sound pressure	N/m^2	N/m^2	N/m^2		1	
Illuminance	lx	footcandle	lx		1.076 391	E+01
Illumination	lx	footcandle	lx		1.076 391	E+01
Irradiance	W/m^2	W/m^2	W/m^2		1	
Light exposure	lx·s	footcandle·s	lx·s		1.076 391	E+01
Luminance	cd/m^2	cd/m^2	cd/m^2		1	
Luminous efficacy	lm/W	lm/W	lm/W		1	

TABLE 2.2—TABLES OF RECOMMENDED SI UNITS (cont'd.)

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
		ACOUSTICS, LIGHT, RADIATION				
Luminous exitance	lm/m^2	lm/m^2	lm/m^2		1	
Luminous flux	lm	lm	lm		1	
Luminous intensity	cd	cd	cd		1	
Quantity of light	ℓm·s	talbot	ℓm·s		1.0*	E+00
Radiance	$W/(m^2{\cdot}sr)$	$W/(m^2{\cdot}sr)$	$W/(m^2{\cdot}sr)$		1	
Radiant energy	J	J	J		1	
Radiant flux	W	W	W		1	
Radiant intensity	W/sr	W/sr	W/sr		1	
Radiant power	W	W	W		1	
Wave length	m	Å	nm		1.0*	E−01
Capture unit	m^{-1}	$10^{-3}cm^{-1}$	m^{-1}		1.0*	E+01
				$10^{-3}cm^{-1}$	1	
		m^{-1}	m^{-1}		1	
Radioactivity		curie	Bq		3.7*	E+10

TABLE 2.3—SOME ADDITIONAL APPLICATION STANDARDS

Quantity and SI Unit		Customary Unit	Metric Unit: SPE Preferred	Metric Unit: Other Allowable	Conversion Factor* Multiply Customary Unit by Factor to Get Metric Unit	
Capillary pressure	Pa	ft (fluid)	m (fluid)		3.048*	E−01
Compressibility of reservoir fluid	Pa^{-1}	psi^{-1}	Pa^{-1}		1.450 377	E−04
				kPa^{-1}	1.450 377	E−01
Corrosion allowance	m	in.	mm		2.54*	E+01
Corrosion rate	m/s	mil/yr (mpy)	mm/a		2.54*	E−02
Differential orifice pressure	Pa	in. H_2O (at 60°F)	kPa		2.488 4	E−01
				cm H_2O	2.54*	E+00
Gas-oil ratio	m^3/m^3	scf/bbl	"standard" m^3/m^3		1.801 175	E−01(1)**
Gas rate	m^3/s	scf/D	"standard" m^3/d		2.863 640	E−02(1)
Geologic time	s	yr	Ma			
Head (fluid mechanics)	m	ft	m		3.048*	E−01
				cm	3.048*	E+01
Heat exchange rate	W	Btu/hr	kW		2.930 711	E−04
				kJ/h	1.055 056	E+00
Mobility	$m^2/Pa·s$	d/cp	$\mu m^2/mPa·s$		9.869 233	E−01
				$\mu m^2/Pa·s$	9.869 233	E+02
Net pay thickness	m	ft	m		3.048*	E−01
Oil rate	m^3/s	bbl/D	m^3/d		1.589 873	E−01
		short ton/yr	Mg/a	t/a	9.071 847	E−01
Particle size	m	micron	μm		1.0*	
Permeability-thickness	m^3	md-ft	md·m	$\mu m^2·m$	3.008 142	E−04
Pipe diameter (actual)	m	in.	cm		2.54*	E+00
				mm	2.54*	E+01
Pressure buildup per cycle	Pa	psi	kPa		6.894 757	E+00(2)
Productivity index	$m^3/Pa·s$	bbl/(psi-D)	$m^3/(kPa·d)$		2.305 916	E−02(2)
Pumping rate	m^3/s	U.S. gal/min	m^3/h		2.271 247	E−01
				L/s	6.309 020	E−02
Revolutions per minute	rad/s	rpm	rad/s		1.047 198	E−01
				rad/m	6.283 185	E+00
Recovery/unit volume (oil)	m^3/m^3	bbl/(acre-ft)	m^3/m^3		1.288 931	E−04
				$m^3/ha·m$	1.288 931	E+00
Reservoir area	m^2	sq mile	km^2		2.589 988	E+00
		acre		ha	4.046 856	E−01
Reservoir volume	m^3	acre-ft	m^3		1.233 482	E+03
				ha·m	1.233 482	E−01
Specific productivity index	$m^3/Pa·s·m$	bbl/(D-psi-ft)	$m^3/(kPa·d·m)$		7.565 341	E−02(2)
Surface or interfacial tension in reservoir capillaries	N/m	dyne/cm	mN/m		1.0*	E+00
Torque	N·m	lbf-ft	N·m		1.355 818	E+00(3)
Velocity (fluid flow)	m/s	ft/s	m/s		3.048*	E−01
Vessel diameter	m					
1-100 cm		in.	cm		2.54*	E+00
above 100 cm		ft	m		3.048*	E−01

*An asterisk indicates the conversion factor is exact using the numbers shown; all subsequent numbers are zeros.

**See Notes 1-3 on page 1598.

TABLE 2.4—FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION CHART

−459.67 to −19

(°C)		(°F)
−273.15	−459.67	
−267.78	−450	
−262.22	−440	
−256.67	−430	
−251.11	−420	
−245.56	−410	
−240.00	−400	
−234.44	−390	
−228.89	−380	
−223.33	−370	
−217.78	−360	
−212.22	−350	
−206.67	−340	
−201.11	−330	
−195.56	−320	
−190.00	−310	
−184.44	−300	
−178.87	−290	
−173.33	−280	
−169.53	−273.15	−459.67
−168.89	−272	−457.6
−167.78	−270	−454.0
−162.22	−260	−436.0
−156.67	−250	−418.0
−151.11	−240	−400.0
−145.56	−230	−382.0
−140.00	−220	−364.0
−134.44	−210	−346.0
−129.89	−200	−328.0
−123.33	−190	−310.0
−117.78	−180	−292.0
−112.22	−170	−274.0
−106.67	−160	−256.0
−101.11	−150	−238.0
−95.56	−140	−220.0
−90.00	−130	−202.0
−84.44	−120	−184.0
−78.89	−110	−166.0
−73.33	−100	−148.0
−70.56	−95	−139.0
−67.78	−90	−130.0
−65.00	−85	−121.0
−62.22	−80	−112.0
−59.45	−75	−103.0
−56.67	−70	−94.0
−53.89	−65	−85.0
−51.11	−60	−76.0
−48.34	−55	−67.0
−45.56	−50	−58.0
−42.78	−45	−49.0
−40.00	−40	−40.0
−39.45	−39	−38.2
−38.89	−38	−36.4
−38.34	−37	−34.6
−37.78	−36	−32.8
−37.23	−35	−31.0
−36.67	−34	−29.2
−36.12	−33	−27.4
−35.56	−32	−25.6
−35.00	−31	−23.8
−34.44	−30	−22.0
−33.89	−29	−20.2
−33.33	−28	−18.4
−32.78	−27	−16.6
−32.22	−26	−14.8
−31.67	−25	−13.0
−31.11	−24	−11.2
−30.56	−23	−9.4
−30.00	−22	−7.6
−29.45	−21	−5.8
−28.89	−20	−4.0
−28.33	−19	−2.2

−18 to 53

(°C)		(°F)
−27.78	−18	−0.4
−27.23	−17	1.4
−26.67	−16	3.2
−26.12	−15	5.0
−25.56	−14	6.8
−25.00	−13	8.6
−24.44	−12	10.4
−23.89	−11	12.2
−23.33	−10	14.0
−22.78	−9	15.8
−22.22	−8	17.6
−21.67	−7	19.4
−21.11	−6	21.2
−20.56	−5	23.0
−20.00	−4	24.8
−19.44	−3	26.6
−18.89	−2	28.4
−18.33	−1	30.2
−17.8	0	32.0
−17.2	1	33.8
−16.7	2	35.6
−16.1	3	37.4
−15.6	4	39.2
−15.0	5	41.0
−14.4	6	42.8
−13.9	7	44.6
−13.3	8	46.4
−12.8	9	48.2
−12.2	10	50.0
−11.7	11	51.8
−11.1	12	53.6
−10.6	13	55.4
−10.0	14	57.2
−9.44	15	59.0
−8.89	16	60.8
−8.33	17	62.6
−7.78	18	64.4
−7.22	19	66.2
−6.67	20	68.0
−6.11	21	69.8
−5.56	22	71.6
−5.00	23	73.4
−4.44	24	75.2
−3.89	25	77.0
−3.33	26	78.8
−2.78	27	80.6
−2.22	28	82.4
−1.67	29	84.2
−1.11	30	86.0
−0.56	31	87.8
0	32	89.6
0.56	33	91.4
1.11	34	93.2
1.67	35	95.0
2.22	36	96.8
2.78	37	98.6
3.33	38	100.4
3.89	39	102.2
4.44	40	104.0
5.00	41	105.8
5.56	42	107.6
6.11	43	109.4
6.67	44	111.2
7.22	45	113.0
7.78	46	114.8
8.33	47	116.6
8.89	48	118.4
9.44	49	120.2
10.0	50	122.0
10.6	51	123.8
11.1	52	125.6
11.7	53	127.4

54 to 350

(°C)		(°F)
12.2	54	129.2
12.8	55	131.0
13.3	56	132.8
13.9	57	134.6
14.4	58	136.4
15.0	59	138.2
15.6	60	140.0
16.1	61	141.8
16.7	62	143.6
17.2	63	145.4
17.8	64	147.2
18.3	65	149.0
18.9	66	150.8
19.4	67	152.6
20.0	68	154.4
20.6	69	156.2
21.1	70	158.0
21.7	71	159.8
22.2	72	161.6
22.8	73	163.4
23.3	74	165.2
23.9	75	167.0
24.4	76	168.8
25.0	77	170.6
25.6	78	172.4
26.1	79	174.2
26.7	80	176.0
27.2	81	177.8
27.8	82	179.6
28.3	83	181.4
28.9	84	183.2
29.4	85	185.0
30.0	86	186.8
30.6	87	188.6
31.1	88	190.4
31.7	89	192.2
32.2	90	194.0
32.8	91	195.8
33.3	92	197.6
33.9	93	199.4
34.4	94	201.2
35.0	95	203.0
35.6	96	204.8
36.1	97	206.6
36.7	98	208.4
37.2	99	210.2
37.8	100	212.0
43.3	110	230.0
48.9	120	248.0
54.4	130	266.0
60.0	140	284.0
65.6	150	302.0
71.1	160	320.0
76.7	170	338.0
82.2	180	356.0
87.8	190	374.0
93.3	200	392.0
98.9	210	410.0
104.4	220	428.0
110.0	230	446.0
115.6	240	464.0
121.1	250	482.0
126.7	260	500.0
132.2	270	518.0
137.8	280	536.0
143.3	290	554.0
148.9	300	572.0
154.4	310	590.0
160.0	320	608.0
165.6	330	626.0
171.1	340	644.0
176.7	350	662.0

360 to 1070

(°C)		(°F)
182.2	360	680.0
187.8	370	698.0
193.3	380	716.0
198.9	390	734.0
204.4	400	752.0
210.0	410	770.0
215.6	420	788.0
221.1	430	806.0
226.7	440	824.6
232.2	450	842.0
237.8	460	860.0
243.3	470	878.0
248.9	480	896.0
254.4	490	914.0
260.0	500	932.0
265.6	510	950.0
271.1	520	968.0
276.7	530	986.0
282.2	540	1,004.0
287.8	550	1,022.0
293.3	560	1,040.0
298.9	570	1,058.0
304.4	580	1,076.0
310.0	590	1,094.0
315.6	600	1,112.0
321.1	610	1,130.0
326.7	620	1,148.0
332.2	630	1,166.0
337.8	640	1,184.0
343.3	650	1,202.0
248.9	660	1,220.0
354.4	670	1,238.0
360.0	680	1,256.0
365.6	690	1,274.0
371.1	700	1,292.0
376.7	710	1,310.0
382.2	720	1,328.0
387.8	730	1,346.0
393.3	740	1,364.0
398.9	750	1,382.0
404.4	760	1,400.0
410.0	770	1,418.0
415.6	780	1,436.0
421.1	790	1,454.0
426.7	800	1,472.0
432.2	810	1,490.0
437.8	820	1,508.0
443.3	830	1,526.0
448.9	840	1,544.0
454.4	850	1,562.0
460.0	860	1,580.0
465.6	870	1,598.0
471.1	880	1,616.0
476.7	890	1,634.0
482.2	900	1,652.0
487.8	910	1,670.0
493.3	920	1,688.0
498.9	930	1,706.0
504.4	940	1,724.0
510.0	950	1,742.0
515.6	960	1,760.0
521.1	970	1,778.0
526.7	980	1,796.0
532.2	990	1,814.0
537.8	1,000	1,832.0
543.3	1,010	1,850.0
548.9	1,020	1,868.0
554.4	1,030	1,886.0
560.0	1,040	1,904.0
565.6	1,050	1,922.0
571.1	1,060	1,940.0
576.7	1,070	1,958.0

1080 to 1790

(°C)		(°F)
582.2	1,080	1,976.0
587.8	1,090	1,994.0
593.3	1,100	2,012.0
598.9	1,110	2,030.0
604.4	1,120	2,048.0
610.0	1,130	2,066.0
615.6	1,140	2,084.0
621.1	1,150	2,102.0
626.7	1,160	2,120.0
632.2	1,170	2,138.0
637.8	1,180	2,156.0
643.3	1,190	2,174.0
648.9	1,200	2,192.0
654.4	1,210	2,210.0
660.0	1,220	2,228.0
665.6	1,230	2,246.0
671.1	1,240	2,264.0
676.7	1,250	2,282.0
682.2	1,260	2,300.0
687.8	1,270	2,318.0
693.3	1,280	2,336.0
698.9	1,290	2,354.0
704.4	1,300	2,372.0
710.0	1,310	2,390.0
715.6	1,320	2,408.0
721.1	1,330	2,426.0
726.7	1,340	2,444.0
732.2	1,350	2,462.0
737.8	1,360	2,480.0
743.3	1,370	2,498.0
748.9	1,380	2,516.0
754.4	1,390	2,534.0
760.0	1,400	2,552.0
765.6	1,410	2,570.0
771.1	1,420	2,588.0
776.7	1,430	2,606.0
782.2	1,440	2,624.0
787.8	1,450	2,642.0
793.3	1,460	2,660.0
798.9	1,470	2,678.0
804.4	1,480	2,696.0
810.0	1,490	2,714.0
815.6	1,500	2,732.0
821.1	1,510	2,750.0
826.7	1,520	2,768.0
832.2	1,530	2,786.0
837.8	1,540	2,804.0
843.3	1,550	2,822.0
848.9	1,560	2,840.0
854.4	1,570	2,858.0
860.0	1,580	2,876.0
865.6	1,590	2,894.0
871.1	1,600	2,912.0
876.7	1,610	2,930.0
882.2	1,620	2,948.0
887.8	1,630	2,966.0
893.3	1,640	2,984.0
898.9	1,650	3,002.0
904.4	1,660	3,020.0
910.0	1,670	3,038.0
915.6	1,680	3,056.0
921.1	1,690	3,074.0
926.7	1,700	3,092.0
932.2	1,710	3,110.0
937.8	1,720	3,128.0
943.3	1,730	3,146.0
948.9	1,740	3,164.0
954.4	1,750	3,182.0
960.0	1,760	3,200.0
965.6	1,770	3,218.0
971.1	1,780	3,236.0
976.7	1,790	3,254.0

1800 to 3000

(°C)		(°F)
982.2	1,800	3,272.0
987.8	1,810	3,290.0
993.3	1,820	3,308.0
998.9	1,830	3,326.0
1,004.4	1,840	3,344.0
1,010.0	1,850	3,362.0
1,015.6	1,860	3,380.0
1,021.1	1,870	3,398.0
1,026.7	1,880	3,416.0
1,032.2	1,890	3,434.0
1,037.8	1,900	3,452.0
1,043.3	1,910	3,470.0
1,048.9	1,920	3,488.0
1,054.4	1,930	3,506.0
1,060.0	1,940	3,524.0
1,065.6	1,950	3,542.0
1,071.1	1,960	3,560.0
1,076.7	1,970	3,578.0
1,082.2	1,980	3,596.0
1,087.8	1,990	3,614.0
1,093.3	2,000	3,632.0
1,098.9	2,010	3,650.0
1,104.4	2,020	3,668.0
1,110.0	2,030	3,686.0
1,115.6	2,040	3,704.0
1,121.1	2,050	3,722.0
1,126.7	2,060	3,740.0
1,132.2	2,070	3,758.0
1,137.8	2,080	3,776.0
1,143.3	2,090	3,794.0
1,148.9	2,100	3,812.0
1,154.4	2,110	3,830.0
1,160.0	2,120	3,848.0
1,165.6	2,130	3,866.0
1,171.1	2,140	3,884.0
1,176.7	2,150	3,907.0
1,182.2	2,160	3,920.0
1,187.8	2,170	3,938.0
1,193.3	2,180	3,956.0
1,198.9	2,190	3,974.0
1,204.4	2,200	3,992.0
1,210.0	2,210	4,010.0
1,215.6	2,220	4,028.0
1,221.1	2,230	4,046.0
1,226.7	2,240	4,064.0
1,232.2	2,250	4,082.0
1,237.8	2,260	4,100.0
1,243.3	2,270	4,118.0
1,248.9	2,280	4,136.0
1,254.4	2,290	4,154.0
1,260.0	2,300	4,172.0
1,265.6	2,310	4,190.0
1,271.1	2,320	4,208.0
1,276.7	2,330	4,226.0
1,282.2	2,340	4,244.0
1,287.8	2,350	4,262.0
1,293.3	2,360	4,280.0
1,298.9	2,370	4,298.0
1,304.4	2,380	4,316.0
1,310.0	2,390	4,334.0
1,343.3	2,450	4,442.0
1,371.1	2,500	4,532.0
1,398.9	2,550	4,622.0
1,426.7	2,600	4,712.0
1,454.4	2,650	4,802.0
1,482.2	2,700	4,892.0
1,510.0	2,750	4,982.0
1,537.8	2,800	5,072.0
1,565.1	2,850	5,162.0
1,593.3	2,900	5,252.0
1,621.1	2,950	5,342.0
1,648.9	3,000	5,432.0

Notes