Appendix

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Standard
METRIC PRACTICE GUIDE*
(A Guide to the Use of SI—the International System of Units)

This Standard is issued under the fixed designation E 380; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

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FOREWORD

The ASTM Board of Directors on 18 January 1971 adopted the following resolution: "It shall be the general policy of the American Society for Testing and Materials to work toward the simplification of units of measurement. To this end, the Society should assume a position of leadership, working with other organizations toward the general national and international use of the International System of Units, generally known as SI." Recognizing the world-wide trend to the use of this modernized metric system,[1] the Society is providing these guidelines for the use of SI in its standards as well as in the standards of commerce and industry. This policy involves no change in standard dimensions, tolerances, or performance specifications.

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[1] An Act of Congress in 1866 declared that "it shall be lawful throughout the United States of America to employ the weights and measures of the metric system." In 1893 an Executive Order directed that "the office of weights and measures ... will in the future regard the international prototype meter and kilogram as fundamental standards, and the customary units, the yard and the pound, will be derived therefrom in accordance with the act of July 28, 1866."

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1. Scope

1.1 This Metric Practice Guide deals with the conversion of quantities in various systems of measurement to the International System of Units,[2] which is officially abbreviated SI in all languages. It includes units most frequently used in the various fields of science and industry.

1.2 The recommendations contained herein are based upon the following premises, which are believed to represent the broadest base for general agreement among proponents of the major metrology systems:

1.2.1 That for most scientific and technical work SI is generally superior to other systems; and that this system is more widely accepted than any other as the common language in which scientific and technical data should be expressed. This is particularly true for the fields of electrical science and technology since the common electrical units (ampere, volt, ohm, etc.) are SI units.

1.2.2 That ASTM recognizes the system described and maintained by the General Conference on Weights and Measures (CGPM) as SI, and along with limited modifications carefully described in this guide will use this system.

1.2.3 That unit usage can and should be simplified; that one means toward such simplification is the elimination of obsolete and unneeded units; and that another is a better understanding of SI.

1.2.4 That certain customary units, both U.S. and "metric," will gradually be phased out of existence, and this and other countries will use the common international measurement language, SI.

2. SI Units and Symbols

2.1 SI consists of seven base units, two supplementary units, a series of derived units consistent with the base and supplementary units, and a series of approved prefixes for the formation of multiples and submultiples of the various units. A number of derived units are listed in 2.1.3 including all approved units with special names (see also Appendix A2.13). Additional derived units without special names are formed as needed from base units or other derived units, or both.

2.1.1 *Base Units:*[3]

Quantity	Unit	SI Symbol	Formula
length	metre	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
amount of substance	mole	mol	...
luminous intensity	candela	cd	...

2.1.2 *Supplementary Units:*[3]

plane angle	radian	rad	...
solid angle	steradian	sr	...

2.1.3 *Derived Units:*

acceleration	metre per second squared	...	m/s^2
activity (of a radioactive source)	disintegration per second	...	(disintegration)/s
angular acceleration	radian per second squared	...	rad/s^2
angular velocity	radian per second	...	rad/s

[2] The International System of Units (Système International d'Unités) (SI) is described in Appendix A2.

[3] The seven base and two supplementary units are defined in Appendix A2.

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Quantity	Unit	SI Symbol	Formula
area	square metre	...	m^2
density	kilogram per cubic metre	...	kg/m^3
electric capacitance	farad	F	A·s/V
electrical conductance	siemens	S	A/V
electric field strength	volt per metre	...	V/m
electric inductance	henry	H	V·s/A
elecfric potential difference	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 metre	...	cd/m^2
luminous flux	lumen	lm	cd·sr
magnetic field strength	ampere per metre	...	A/m
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m^2
magnetomotive force	ampere	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 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 metre-kelvin	...	W/m·K
velocity	metre per second	...	m/s
viscosity, dynamic	pascal-second	...	Pa·s
viscosity, kinematic	square metre per second	...	m^2/s
voltage	volt	V	W/A
volume[4]	cubic metre	...	m^3
wavenumber	reciprocal metre	...	(wave)/m
work	joule	J	N·m

2.1.4 *SI Prefixes* (*see 3.2*):

Multiplication Factors		Prefix	SI Symbol
1 000 000 000 000	= 10^{12}	tera	T
1 000 000 000	= 10^9	giga	G
1 000 000	= 10^6	mega	M
1 000	= 10^3	kilo	k
100	= 10^2	hecto*	h
10	= 10^1	deka*	da
0.1	= 10^{-1}	deci*	d
0.01	= 10^{-2}	centi*	c
0.001	= 10^{-3}	milli	m
0.000 001	= 10^{-6}	micro	μ
0.000 000 001	= 10^{-9}	nano	n
0.000 000 000 001	= 10^{-12}	pico	p
0.000 000 000 000 001	= 10^{-15}	femto	f
0.000 000 000 000 000 001	= 10^{-18}	atto	a

*To be avoided where possible. See 3.2.2 and 3.2.5

3. Rules for SI Style and Usage

3.1 *General*—The established SI units—base, supplementary, derived, and combinations thereof (see Section 2, SI Units and Symbols) with appropriate multiple or submultiple prefixes—should be used. To main-

[4] In 1964 the General Conference on Weights and Measures adopted the name litre as a special name for the cubic decimetre but discouraged the use of the name litre for volume measurement of extreme precision.

tain the coherence of the system, multiples or submultiples of SI units should not be used in calculations.

3.1.1 *Mixed Units*—The use of mixed units, especially those compounded from different systems, should be avoided. For example,

use kilogram per cubic metre (kg/m^3), not kilogram per gallon (kg/gal),
use 0.1789 rad or 10.25 deg, not 10 deg 15 min, and
use 12.75 lb, not 12 lb 12 oz.

3.2 *Application of Prefixes:*

3.2.1 *General*—SI prefixes (2.1.4) should be used to indicate orders of magnitude, thus eliminating insignificant digits and decimals, and providing a convenient substitute for writing powers of 10 as generally preferred in computation. For example,

12 300 m or 12.3×10^3 m becomes 12.3 km, and
0.0123 μA or 12.3×10^{-9} A becomes 12.3 nA.

3.2.2 *Selection*—Multiple and submultiple prefixes representing steps of 1000 are recommended. For example, show force in mN, N, kN, and length in mm, m, km, etc. The use of centimetres should be avoided unless a strong reason exists. An exception is made in the case of area and volume used alone (see 3.2.5). When expressing a quantity by a numerical value and a unit, prefixes should preferably be chosen so that the numerical value lies between 0.1 and 1000, except where certain multiples or submultiples have been agreed to for particular use. The same unit, multiple, or submultiple is used for tabular values even though the series exceeds the preferred range 0.1 to 1000.

3.2.3 Double prefixes and hyphenated prefixes should not be used. For example,

use GW (gigawatt), not kMW,
use pF (picofarad), not μμF, and
use Gg (gigagram), not Mkg.

3.2.4 *Combination Units*—Prefixes should not be used in the denominator of compound units, except for the kilogram (kg). Since the kilogram is a base unit of SI, this particular multiple is not a violation and should be used in place of the gram; for example, use 2 kJ/kg, not 2 J/g. Prefixes may be applied to the numerator of a combination unit, thus, megagram per cubic metre (Mg/m^3) or for greater clarity, mega(gram per cubic metre), but *not* kilogram per cubic decimetre (kg/dm^3) *nor* gram per cubic centimetre (g/cm^3).

3.2.5 With SI units of higher order such as m^2 and m^3, the prefix is also raised to the same order; for example, mm^3 is 10^{-9} m^3 not 10^{-3} m^3. In such cases, the use of cm^2, cm^3, dm^2, dm^3, and similar nonpreferred prefixes is permissible.

3.2.6 Among the base units of SI, the unit for mass is the only one whose name, for historical reasons, contains a prefix. Names of decimal multiples and submultiples of the unit of mass are formed by attaching prefixes to the word "gram."

3.3 *Non-SI Units*—The use of units that are not SI should be limited to those for temperature, time, and angle, given in 3.4.3, 3.4.4, and 3.4.5, respectively.

3.4 *Usage for Selected Quantities:*

3.4.1 *Mass, Force, and Weight:*

3.4.1.1 The principal departure of SI from the gravimetric form of metric engineering units is the separate and distinct units for mass and force. The kilogram is restricted to the unit of mass. The newton is the unit of force and should be used in place of kilogram-force. Likewise, the newton instead of kilogram-force should be used in combination units which include force, for example, pressure or stress (N/m^2 = Pa), energy ($N \cdot m$ = J), and power ($N \cdot m/s$ = W).

3.4.1.2 Considerable confusion exists in the use of the term *weight* to mean either *force* or *mass*. In scientific use the term *weight* of a body usually means the force which if applied to the body would give it acceleration equal to the local acceleration of free fall. This acceleration varies in time and space; and *weight*, if used to mean force, varies also, as observed values differ by over 0.5 % at various points on the earth's surface. In commercial and everyday use, on the other hand, the term weight nearly always means mass. Thus when one speaks of a person's weight, the quantity referred to is mass. Because of this dual use, the term weight should be avoided 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 clarified in 3.4.1.1 above by using kilograms for mass or newtons for force.

3.4.1.3 Gravity is involved in determining mass with a balance or scale. When using a standard mass to balance the measured mass, the effect of gravity on the two masses is canceled. 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 is not significant in their use.

3.4.1.4 The relationship between newtons, kilograms, metres, and seconds given by the first law of motion ($F = ma$) should be used to simplify units (that is, $N = kg \cdot m/s^2$). Thus, the combination unit of foot-pound-force per pound-mass used to measure efficiency may be converted to newton-metre per kilogram ($N \cdot m/kg$) or joule per kilogram (J/kg), but it must not be converted to metre since pound-force and pound-mass are not equivalent units.

3.4.1.5 The use of the same name for units of force and mass causes confusion. When non-SI units are used, a distinction should be made between (*1*) force and (*2*) mass, for example, lbf to denote force in gravimetric engineering units and lb for mass.

3.4.1.6 Common use has been made of the metric ton, also called *tonne* (exactly 1 Mg) in previously metric countries. This use is strongly discouraged, and such large masses should be measured in megagrams.

3.4.2 *Length:*

3.4.2.1 Nominal dimensions name the item; no SI equivalent is required (see Appendix A1 for definition of "nominal"). For example, there is nothing 1 in. about a nominal "1-in. pipe," the dimensions of which should be converted as follows:

Nominal Size, in.	Outside Diameter, in. (mm)	Wall Thickness, in. (mm)		
		Sch 40	Sch 80	Sch 160
1	1.315 (33.40)	0.133 (3.38)	0.179 (4.55)	0.250 (6.35)

Likewise, a "2 by 4" is that in name only and refers to the approximate dimensions in inches of a rough-sawn, green piece of timber, the finished dimensions of which are considerably less. A ¼-20 UNC screw thread should continue to be identified in this manner. However, the controlling dimensions of the part, such as the pitch, major, and minor diameters of a screw thread, should be converted to SI values in accordance with 3.1 and 3.2. Threads per inch should be converted to millimetre pitch.

3.4.2.2 When a dimension such as wire diameter or thickness of sheet and strip is expressed by a gage number, the appropriate gage system[3] (for example, American Wire Gage or Awg) and the corresponding SI value should be given.

3.4.2.3 Surface finish expressed in microinch should be converted to micrometre (μm).

3.4.3 *Temperature*—The SI temperature scale is the International Thermodynamic Temperature Scale, and the SI unit used is the kelvin; therefore kelvins should be used to express temperature and temperature intervals as the preferred unit. However, wide use is made of the degree Celsius, particularly in engineering and in non-scientific areas, and it is permissible to use the Celsius scale where considered necessary. The Celsius scale (formerly called the centigrade scale) is related directly to the kelvin scale as follows:

One degree Celsius equals one kelvin, exactly.
A Celsius temperature (t) is related to a kelvin temperature (T) as follows:

$$T = 273.15 + t, \text{ exactly}$$

In using temperature information of extreme precision, the International Practical Temperature Scale must be recognized, because much available data are based upon it. This consists of international agreement on certain fixed points to permit calibration of instruments. Some of these fixed points are known to contain errors, but the differences between the Thermodynamic and the Practical scales are of no consequence in almost all temperature considerations. The basis of the practical scale is given in Footnote 9 (see A2.12.5).

3.4.4 *Time*—The SI unit for time is the second. This unit is preferred and should be used when technical calculations are involved. In other cases use of the minute, hour, day, etc., is permissible.

3.4.5 *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. Solid angles should be expressed in steradians.

3.4.6 *Stress and Pressure*—The SI unit for

pressure and stress is the pascal (newton per square metre). The use of the metric engineering units—kilogram-force per square centimetre, kilogram-force per square millimetre, bar, torr, etc.—is discouraged and should be discontinued.

3.4.6.1 It has been internationally recommended that pressure units themselves should not be modified to indicate whether the pressure is "absolute" (that is, above zero) or "gage" (that is, above atmospheric pressure). If, therefore, the context leaves any doubt as to which is meant, the word "pressure" must be qualified appropriately:

". . . . at a gage pressure of 13 kPa" or
". . . . at an absolute pressure of 13 kPa" or
". . . . reached an absolute pressure of 13 kPa" etc.

3.4.7 *Other Quantities*—The use of other non-SI units (for example, metric horsepower for power and calorie for energy) should be discontinued as rapidly as possible.

3.5 *Style:*

3.5.1 *Capitalization*—Symbols for SI units are not capitalized unless the unit is derived from a proper name; thus, Hz (hertz) from H. R. Hertz, but m for metre. Unabbreviated units are not capitalized, for example, hertz, newton, and kelvin. Numerical prefixes and their symbols are not capitalized, except for the symbols T, G, and M (mega) (see 2.1.4).

3.5.2 *Plurals*—Unabbreviated SI units form their plurals in the usual manner. SI symbols are always written in singular form, for example:

50 newtons or 50 N, and
25 grams or 25 g.

3.5.3 *Punctuation*—Periods should not be used after SI unit symbols except at the end of a sentence.

3.5.4 *Number Grouping*—To facilitate the reading of numbers having five or more digits, the digits should be placed in groups of three separated by a space instead of commas counting both to the left and to the right of the decimal point. In the case of four digits the spacing is optional. This style also avoids confusion caused by the European use of commas to express decimal points. For example, use

1 532 or 1532 instead of 1,532
132 541 816 instead of 132,541,816
983 769.816 78 instead of 983,769.81678

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

3.5.6 *Derived Units*—In derived unit symbols, use the center dot to indicate multiplication and a slash to indicate division. Symbols to the left of the slash are in the numerator and those to the right in the denominator.

4. Rules for Conversion and Rounding

4.1 *General:*

4.1.1 Appendix A3 contains conversion factors that give exact or seven-figure accuracy for implementing these rules except where the nature of the dimension makes this impractical.

4.1.2 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.

4.1.3 Proper conversion procedure is to multiply the specified quantity by the conversion factor exactly as given in Appendix A3 and then round to the appropriate number of significant digits. For example, to convert 11.4 ft to metres: $11.4 \times 0.3048 = 3.474\ 72$, which rounds to 3.47 m. Do not round either the conversion factor or the quantity before performing the multiplication, as accuracy would be reduced.

4.2 *Accuracy and Rounding*—Accurate conversions are obtained by multiplying the specified quantity by the appropriate conversion factor given in Appendix A3. However, this product will usually imply an accuracy not intended by the original value. Proper conversion technique includes rounding this 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 1/16ths of an inch is suitable for making the original meas-

urements, 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 gage or caliper graduated in divisions of 0.02 mm is comparable to one graduated in divisions of 0.001 in., and equivalents should be similarly indicated. Analogous situations exist in mass, force, and other measurements. Many techniques are used to guide the determination of the proper number of significant digits in the converted values. Two different approaches to rounding of quantities are here described—one for general use and the other for conversion of dimensions involving mechanical interchangeability.

4.2.1 *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. This precision should relate to the number of digits in the original, but in many cases this is not a reliable indicator. A figure 1.1875 may be a very accurate decimalization of a noncritical 1 3/16ths that should have been expressed 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 have been written 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, and should usually 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 4.3) 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 this is 12.7 mm. The converted dimension 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.

4.2.2 *Special Cases:*

4.2.2.1 Converted values should be rounded to the minimum number of significant digits that will maintain the required accuracy, as discussed above. In certain cases deviation from this practice to make use of convenient or whole numbers may be feasible, in which case the word "approximate" must be used following the conversion. For example,

1 ⅞ in. 47.625 mm exact
47.6 mm normal rounding
47.5 mm (approx) rounded to preferred number
48 mm (approx) rounded to whole number

4.2.2.2 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 at least 102 mm.

4.3 *Significant Digits*[5]:

4.3.1 When converting integral values of units, consideration must be given to the implied or required precision of the integral value to be converted. For example, the value "4 in." may be intended to represent 4, 4.0, 4.00, 4.000, 4.0000 in., or even greater accuracy. Obviously, the converted value must be carried to a sufficient number of digits to maintain the accuracy implied or required in the original quantity.

4.3.2 Any digit that is necessary to define the specific value or quantity is said to be significant. When measured to the nearest 1 m, a distance may be 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; this number has four significant digits. In each of these cases 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

[5] See also ASTM Recommended Practice E 29, for Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values, *Annual Book of ASTM Standards*, Part 41.

words, 157.4 was rounded to 157; in the second case, the measurement in hundredths, 157.36 was rounded to 157.4.

4.3.3 Zeros may be used either to indicate a specific value, like any other digit, or to indicate the magnitude of a number. The 1960 U.S. population figure rounded to thousands was 179 323 000. The six left-hand digits of this number are significant; each of them *measures* a value. The three right-hand digits are zeros which merely indicate the *magnitude* of the number rounded to the nearest thousand. This point may be further illustrated by the following list of estimates and measurements, each of which is of different magnitude but each of which has only one significant digit:

1000
100
10
0.01
0.001
0.0001

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

4.3.4 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*.

4.3.4.1 The rule for addition and subtraction is that the *answer* shall contain no significant digits farther to the right than occurs in the least accurate figure. 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
```

The 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 accurate number, and the sum taken as follows:

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

The answer is then 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 0 following 218 would have been a significant digit.

4.3.4.2 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; the latter rule merely requires rounding of digits that lie to the right of the last significant digit in the least accurate number. The following illustration highlights this difference:

Multiplication:	113.2 × 1.43 = 161.876, rounded to 162
Division:	113.2 ÷ 1.43 = 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.

4.3.4.3 Numbers used in the above illustrations have all been estimates or measurements. Numbers that are exact counts are treated as though they consist of an infinite number of significant digits. More simply stated, 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 but one significant digit, the product would be 400.

4.4 *Rounding Values*[6]:

[6] Adapted from "American National Standard Practice for Inch-Millimeter Conversion for Industrial Use," ANSI B48.1-1933 (R1947), ISO R370—1964.

4.4.1 When a figure is to be rounded to fewer digits then the total number available, the procedure should be as follows:

4.4.1.1 When the first digit discarded is less than 5, the last digit retained should not be changed. For example, 3.463 25, if rounded to four digits, would be 3.463; if rounded to three digits, 3.46.

4.4.1.2 When the first digit discarded is greater than 5, or if it is a 5 followed by at least one digit other than 0, the last figure retained should be increased by one unit. For example 8.376 52, if rounded to four digits, would be 8.377; if rounded to three digits, 8.38.

4.4.1.3 When the first digit discarded is exactly 5, followed only by zeros, the last digit retained should be rounded upward if it is an odd number, but no adjustment made if it is an even number. For example, 4.365, when rounded to three digits, becomes 4.36. 4.355 would also round to the same value, 4.36, if rounded to three digits.

4.5 *Conversion of Linear Dimensions of Interchangeable Parts*—The use of the exact relation 1 in. = 25.4 mm generally produces converted values containing more decimal places than are required for the desired accuracy. It is therefore, necessary to round these values suitably and at the same time maintain the degree of accuracy in the converted values compatible with that of the original values.

4.5.1 *General*—The number of decimal places given in Table 1 for rounding toleranced dimensions relates the degree of accuracy to the size of the tolerances specified. Two methods of using this table are given: Method A, which rounds to values nearest to each limit, and Method B, which rounds to values always inside the limits.

In Method A, rounding is effected to the nearest rounded value of the limit, so that, on the average, the converted tolerances remain statistically identical with the original tolerances. The limits converted by this method, where acceptable for interchangeability, serve as a basis for inspection.

In Method B, rounding is done systematically *toward the interior* of the tolerance zone so that the converted tolerances are never larger than the original tolerances. This method must be employed when the original limits have to be respected absolutely, in particular, when components made to converted limits are to be inspected by means of original gages.

Method A—The use of this method ensures that even in the most unfavorable cases neither of the two original limits will be changed by more than 2 % of the value of the tolerance. Proceed as follows:

(*a*) Calculate the maximum and minimum limits in inches.

(*b*) Convert the corresponding two values exactly into millimetres by means of the conversion factor 1 in. = 25.4 mm (see Table 2).

(*c*) Round the results obtained to the nearest rounded value as indicated in Table 1, depending on the original tolerance in inches, that is, on the difference between the two limits in inches.

Method B—This method must be employed when the original limits may not be violated, for instance, certain critical mating parts. In extreme cases, this method may increase the lower limit a maximum of 4 % of the tolerance and decrease the upper limit a maximum of 4 % of the tolerance.

(*a*) Proceed as in Method A, steps (*a*) and (*b*).

(*b*) Round each limit toward the interior of the tolerance, that is, to the next lower value for the upper limit and to the next higher value for the lower limit,[7] for example:

A dimension is expressed in inches as	1.950 ± 0.016
The limits are	1.934 to 1.966
Conversion of the two limits into millimetres gives	49.1236 to 49.9364
Method A—The tolerance equals 0.032 in. and thus lies between 0.01 and 0.1 in. (see Table 1). Rounding these values to the nearest 0.01 mm, the values in millimetres to be employed for these two limits are	49.12 to 49.94
Method B—Rounding toward the interior of the tolerance, millimetre values for these two limits are	49.13 to 49.93

This reduces the tolerance to 0.80 instead of 0.82 mm given by Method A.

4.5.2 *Special Method for Plus and Minus Toleranced Dimensions*—In order to avoid accumulation of rounding errors, the two limits of size normally are converted sepa-

[7] If the digits to be rounded are zeros, the retained digits remain unchanged.

rately: thus, they must first be calculated if the dimension consists of a basic size and two tolerances. However (except when Method B is specified) as an alternative, the basic size may be converted to the nearest rounded value and each of the tolerances converted toward the interior of the tolerance. This method, which sometimes makes conversion easier, gives the same maximum guarantee of accuracy as Method A, but usually results in smaller converted tolerances.

4.5.3 *Special Methods for Limitation Imposed by Accuracy of Measurements*—If the increment of rounding given for the tolerances in Table 1 is too small for the available accuracy of measurement, limits that are acceptable for interchangeability must be determined separately for the dimensions. For example, where accuracy of measurement is limited to 0.001 mm, study shows that values converted from 1.0000 ± 0.0005 in. can be rounded to 25.413 and 25.387 mm instead of 25.4127 and 25.3873 mm with little disadvantage, since neither of the two original limits is exceeded by more than 1.2 % of the tolerance.

4.5.4 *Positional Tolerance*—If the dimensioning consists solely of a positional tolerance around a point defined by a nontoleranced basic dimension, the basic dimension must be converted to the nearest rounded value and the positional variation (radius) separately converted by rounding downwards.

4.5.5 *Toleranced Dimension Applied to a Nontoleranced Position Dimension*—If the toleranced dimension is located in a plane, the position of which is given by nontoleranced basic or gage dimension, such as when dimensioning certain conical surfaces, proceed as follows:

(*a*) Round the converted reference gage arbitrarily, to the nearest convenient value.

(*b*) Calculate exactly, in the converted unit of measurement, new maximum and minimum limits of the specified tolerance zone, in the new plane defined by the new basic dimension.

(*c*) Round these limits in conformity with the rules given in 4.4. For example, a cone of taper 0.05 in./in. has a diameter of 1.000 ± 0.002 in. in a reference plane located by the nontoleranced dimension 0.9300 in. By virtue of the taper of the cone, the limits of the tolerance zone depend on the position of the reference plane. Consequently, if the dimension 0.9300 in. = 23.6220 mm is rounded to 23.600 mm, that is, a reduction of 0.022 mm, each of the two original limits, when converted exactly into millimetres, must be corrected by 0.022 × 0.05 = 0.0011 mm, in the appropriate sense, before being rounded.

4.5.6 *Consideration of Maximum and Minimum Material Condition*—The ability to assemble mating parts depends on a "go" condition at the maximum material limits of the parts. The minimum material limits, which are determined by the respective tolerances, are often not as critical from a functional standpoint. Accordingly, it may be desirable to employ a combination of Methods A and B in certain conversions by using Method B for the maximum material limits and Method A for the minimum material limits. Alternatively, it may be desirable to round automatically the converted minimum material limits outside the original limits to provide greater tolerances for manufacturing.

4.5.7 While the technique described here in 4.5 provides good accuracy of conversion, it will often result in dimensions that are impractical for actual production use. For conversions intended for production, it is usually necessary to round to fewer decimal places and apply design judgment to each dimension to assure interchangeability.

4.6 *Other Units:*

4.6.1 *Temperature*—General guidance for converting tolerances from degrees Fahrenheit to kelvins or degrees Celsius is given in Table 3. Normally, temperatures expressed in a whole number of degrees Fahrenheit should be converted to the nearest 0.5 kelvin (or degree Celsius). As with other quantities the number of significant digits to retain will depend upon implied accuracy of the original dimension.

100 ± 5°F implied accuracy estimated total 2°F. 37.7777 ± 2.7777°C rounds to 38 ± 3°C.

1000 ± 50°F implied accuracy estimated total 20°F. 537.7777 ± 27.7777°C rounds to 540 ± 30°C.

4.6.2 *Pressure or Stress*—As with other quantities, pressure or stress values may be converted by the principle given above. Values

with an uncertainty of more than 2 % may be converted without rounding by the approximate factors:

1 psi = 7 kN/m² = 7 kPa
1 ksi = 7 MN/m² = 7 MPa

For conversion factors and values see Appendix A3 and Tables 4 and 5.

4.7 *Use of Tables:*

4.7.1 As an alternative to calculating conversions, conversion tables and charts are frequently provided for the rapid determination of converted values of commonly used quantities by addition only. Table 2 is of this type, and provides values for converting inches to millimetres. In using this table, the inch value to be converted should be written to as many decimal places as accuracy requires. The value should then be split into groups of not more than two significant digits each. The inch equivalent of each group should be taken from Table 2 and tabulated as in the following example, proper regard being given to the position of the decimal point in each case. For example, to convert 2.4637 in. to millimetres,

2.0000 in.	=	50.800 00 mm exactly
0.4600 in.	=	11.684 00 mm exactly
0.0037 in.	=	0.093 98 mm exactly
2.4637 in.	=	62.577 98 mm exactly

or rounded to three decimal places:

2.4637 in. = 62.578 mm

In this example, to maintain accuracy during conversion without retaining an unnecessary number of digits, the rounded millimetre equivalent of each group is carried to one decimal place more than the inch value being converted. The sum of the group of equivalents is then rounded to one less decimal place than the original inch value.

4.7.2 Table 6 provides values for the conversion of decimal and fractional values of an inch to millimetres. Combinations of inch and fractional inch-millimetre equivalents may be tabulated to obtain the desired millimetre conversion. As in the example in 4.7.1 the millimetre value should be rounded to one less decimal place than the decimal equivalent of the inch fraction taken to the intended or implied accuracy.

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TABLE 1 Rounding Tolerances

Inches to Millimetres

Original Tolerance, in.		Fineness of Rounding, mm
at least	less than	
0.000 01	0.000 1	0.000 01
0.000 1	0.001	0.000 1
0.001	0.01	0.001
0.01	0.1	0.01
0.1	1	0.1

TABLE 2 Inch-Millimetre Equivalents

NOTE—All values in this table are exact, based on the relation 1 in. = 25.4 mm. By manipulation of the decimal point any decimal value or multiple of an inch may be converted to its exact equivalent in millimetres.

in.	0	1	2	3	4	5	6	7	8	9
						mm				
0		25.4	50.8	76.2	101.6	127.0	152.4	177.8	203.2	228 6
10	254.0	279.4	304.8	330.2	355.6	381.0	406.4	431.8	457.2	482 6
20	508.0	533.4	558.8	584.2	609.6	635.0	660.4	685.8	711.2	736 6
30	762.0	787.4	812 8	838.2	863.6	889.0	914 4	939 8	965.2	990.6
40	1016.0	1041.4	1066.8	1092.2	1117.6	1143 0	1168 4	1193 8	1219.2	1244.6
50	1270.0	1295.4	1320.8	1346.2	1371.6	1397 0	1422.4	1447.8	1473.2	1498.6
60	1524.0	1549.4	1574.8	1600.2	1625.6	1651.0	1676.4	1701.8	1727.2	1752.6
70	1778.0	1803.4	1828.8	1854.2	1879.6	1905.0	1930.4	1955.8	1981.2	2006.6
80	2032.0	2057.4	2082.8	2108.2	2133.6	2159 0	2184.4	2209.8	2235 2	2260.6
90	2286.0	2311.4	2336.8	2362.2	2387.6	2413.0	2438.4	2463.8	2489.2	2514 6
100	2540.0	2565.4	2590.8	2616.2	2641.6	2667.0	2692.4	2717.8	2743.2	2768.6

TABLE 3 Conversion of Temperature Tolerance Requirements

Tolerance, °F	±1	±2	±5	±10	±15	±20	±25
Tolerance, K or °C	±0 5	±1	±3	±5.5	±8.5	±11	±14

TABLE 4 Pressure and Stress Equivalents—Pounds-Force per Square Inch and Thousand Pounds-Force per Square Inch to Kilopascals (Kilonewtons per Square Metre) and Megapascals (Meganewtons per Square Metre)

NOTE 1—This table may be used to obtain SI equivalents of values expressed in psi or ksi. SI values are usually expressed in kPa (kN/m^2) when original value is in psi and in MPa (MN/m^2) when original value is in ksi.

NOTE 2—This table may be extended to values below 1 or above 100 psi (ksi) by manipulation of the decimal point and addition as illustrated in 4.7.1.

Conversion Relationships: 1 in. = 0.0254 m (exactly)
1 lbf = 4.448 221 615 260 5 N (exactly)

psi ksi	0	1	2	3	4	5	6	7	8	9
	kPa (kN/m^2) MPa (MN/m^2)									
0	0.0000	6.8948	13.7895	20.6843	27.5790	34.4738	41.3685	48.2633	55.1581	62.0528
10	68.9476	75.8423	82.7371	89.6318	96.5266	103.4214	110.3161	117.2109	124.1056	131.0004
20	137.8951	144.7899	151.6847	158.5794	165.4742	172.3689	179.2637	186.1584	193.0532	199.9480
30	206.8427	213.7375	220.6322	227.5270	234.4217	241.3165	248.2113	255.1060	262.0008	268.8955
40	275 7903	282.6850	289.5798	296.4746	303.3693	310.2641	317.1588	324.0536	330.9484	337.8431
50	344.7379	351.6326	358.5274	365.4221	372.3169	379. 2117	386.1064	393.0012	399.8959	406.7907
60	413.6854	420.5802	427.4750	434.3697	441.2645	448.1592	455.0540	461.9487	468.8435	475.7383
70	482.6330	489.5278	496.4225	503.3173	510.2120	517.1068	524.0016	530.8963	537.7911	544.6858
80	551.5806	558.4753	565 3701	572.2649	579 1596	586.0544	592.9491	599.8439	606.7386	613.6334
90	620.5282	627.4229	634.3177	641.2124	648.1072	655 0019	661.8967	668.7915	675.6862	682.5810
100	689.4757	696.3705	703.2652	710.1600	717.0548	723.9495	730.8443	737.7390	744.6338	751.5285

TABLE 5 Pressure and Stress Equivalents—Metric Engineering to SI Units

NOTE 1—This table may be used for obtaining SI equivalents of quantities expressed in kgf/cm² by multiplying the given values by 10^{-2}, that is, by moving the decimal point two places to the left.

NOTE 2—This table may be extended to values below 1 or above 100 kgf/cm² by manipulation of the decimal point and addition as illustrated in 4.7.1.

Conversion Relationships: 1 mm = 0.001 m (exactly)
1 kgf = 9.80665 N (exactly)

	0	1	2	3	4	5	6	7	8	9
kgf/mm²					MPa (MN/m²)					
0		9.8066	19.6133	29.4200	39.2266	49.0332	58.8399	68.6466	78.4532	88.2598
10	98.0665	107.8732	117.6798	127.4864	137.2931	147.0998	156.9064	166.7130	176.5197	186.3264
20	196.1330	205.9396	215.7463	225.5530	235.3596	245.1662	254.9729	264.7796	274 5862	284.3928
30	294.1995	304.0062	313.8128	323.6194	333.4261	343.2328	353.0394	362.8460	372.6527	382.4594
40	392.2660	402.0726	411.8793	421.6860	431.4926	441.2992	451.1059	460.9126	470.7192	480.5258
50	490.3325	500.1392	509.9458	519.7524	529.5591	539.3658	549.1724	558.9790	568.7857	578.5924
60	588.3990	598.2056	608.0123	617.8190	627.6256	637.4322	647.2389	657.0456	666.8522	676.6588
70	686.4655	696.2722	706.0788	715.8854	725.6921	735.4988	745.3054	755.1120	764.9187	774.7254
80	784.5320	794.3386	804.1453	813.9520	823.7586	833.5652	843.3719	853.1786	862.9852	872.7918
90	882.5985	892.4052	902.2118	912.0184	921.8251	931.6318	941.4384	951.2450	961.0517	970.8584
100	980.6650	990.4716	1000.2783	1010.0850	1019.8916	1029.6982	1039.5049	1049.3116	1059.1182	1068.9248

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TABLE 6 Inch-Millimetre Equivalents of Decimal and Common Fractions

From 1/64 to 1 in.

NOTE: **Caution**—Convert only to the number of decimal places consistent with the intended or implied accuracy.

Inch	½'s	¼'s	8ths	16ths	32nds	64ths	Decimals of an Inch[a]	Millimetres
						1	0.015 625	0.397
					1	2	0.031 25	0.794
						3	0.046 875	1.191
				1	2	4	0.062 5	1.588
						5	0.078 125	1.984
					3	6	0.093 75	2.381
						7	0.109 375	2.778
			1	2	4	8	0.125 0	3.175[a]
						9	0.140 625	3.572
					5	10	0.156 25	3.969
						11	0.171 875	4.366
				3	6	12	0.187 5	4.762
						13	0.203 125	5.159
					7	14	0.218 75	5.556
						15	0.234 375	5.953
		1	2	4	8	16	0.250 0	6.350[a]
						17	0.265 625	6.747
					9	18	0.281 25	7.144
						19	0.296 875	7.541
				5	10	20	0.312 5	7.938
						21	0.328 125	8.334
					11	22	0.343 75	8.731
						23	0.359 375	9.128
			3	6	12	24	0.375 0	9.525[a]
						25	0.390 625	9.922
					13	26	0.406 25	10.319
						27	0.421 875	10.716
				7	14	28	0.437 5	11.112
						29	0.453 125	11.509
					15	30	0.468 75	11.906
						31	0.484 375	12.303
	1	2	4	8	16	32	0.500 0	12.700[a]
						33	0.515 625	13.097
					17	34	0.531 25	13.494
						35	0.546 875	13.891
				9	18	36	0.562 5	14.288
						37	0.578 125	14.684
					19	38	0.593 75	15.081
						39	0.609 375	15.478
			5	10	20	40	0.625 0	15.875[a]
						41	0.640 625	16.272
					21	42	0.656 25	16.669
						43	0.671 875	17.066
				11	22	44	0.687 5	17.462
						45	0.703 125	17.859
					23	46	0.718 75	18.256
						47	0.734 375	18.653
		3	6	12	24	48	0.750 0	19.050[a]
						49	0.765 625	19.447
					25	50	0.781 25	19.844
						51	0.796 875	20.241
				13	26	52	0.812 5	20.638

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TABLE 6—*Continued*

Inch	½'s	¼'s	8ths	16ths	32nds	64ths	Decimals of an Inch[a]	Millimetres
						53	0.828 125	21.034
					27	54	0.843 75	21.431
						55	0.859 375	21.828
			7	14	28	56	0.875 0	22.225[a]
						57	0.890 625	22.622
					29	58	0.906 25	23.019
						59	0.921 875	23.416
				15	30	60	0.937 5	23.812
						61	0.953 125	24.209
					31	62	0.968 75	24.606
						63	0.984 375	25.003
1	2	4	8	16	32	64	1.000 0	25.400[a]

[a] Exact.

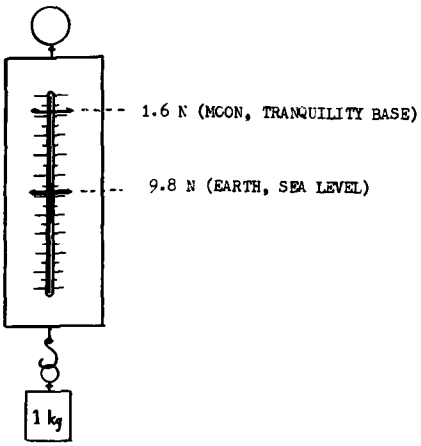

FIG. 1 Illustration of Difference Between Mass (Unit = Kilogram) and Force (Unit = Newton).

APPENDIXES

A1. TERMINOLOGY

A1.1 To help ensure consistently reliable conversion and rounding practices, a clear understanding of the related nontechnical terms is a prerequisite. Accordingly, certain terms used in this Guide 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—describes a value that is nearly but not exactly correct or accurate.

deviation—variations from a specified dimension or design requirement, usually defining upper and lower limits. (See also **tolerance**.)

digit—one of the ten Arabic numerals (0 to 9) by which all numbers are expressed.

dimension—a geometric element in a design, such as length, angle, etc., or the magnitude of such a quantity.

feature—an individual characteristic of a part, such as screw-thread, taper, slot, etc.

figure (numerical)—an arithmetic value expressed by one or more digits.

nominal—describes a value assigned for the purpose of convenient designation; existing in name only.

precision (as distinguished from **accuracy**)—the degree of mutual agreement between individual measurements, namely repeatability and reproducibility.

significant (as applied to a digit)—any digit that is necessary to define a value or quantity (see Footnote 5).

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 upon the yard and the pound commonly used in the United States of America and defined by the National Bureau of Standards (Ref 14). Some of these units have the same name as similar units in the United Kingdom (British, English, or U.K. units) but are not necessarily equal to them.

A2. DEVELOPMENT OF THE INTERNATIONAL SYSTEM OF UNITS

Le Système International d'Unités

A2.1 The decimal system of units was first conceived in the 16th century when there was a great confusion and jumble of units of weights and measures. It was not until 1790, however, that the French National Assembly requested the French Academy of Sciences to work out a system of units suitable for adoption by the entire world. This system, based on the metre as a unit of length and the gram as a unit of mass, was adopted as a practical measure to benefit industry and commerce. Physicists soon realized its advantages and it was adopted also in scientific and technical circles. The importance of the regulation of weights and measures was recognized in Article 1, Section 8, when the United States Constitution was written in 1787, but the metric system was not legalized in this country until 1866. In 1893, the international metre and kilogram became the fundamental standards of length and mass in the United States, both for metric and customary weights and measures.

A2.2 Meanwhile, international standardization began with an 1870 meeting of 15 nations in Paris that led to the May 20, 1875, International Metric Convention, and the establishment of a permanent International Bureau of Weights and Measures near Paris. A General Conference on Weights and Measures (CGPM) was also constituted to handle all international matters concerning the metric system. The CGPM nominally meets every sixth year in Paris and controls the International Bureau of Weights and Measures which preserves the metric standards, compares national standards with them, and conducts research to establish new standards. The National Bureau of Standards represents the United States in these activities.

A2.3 The original metric system provided a coherent set of units for the measurement of length, area, volume, capacity, and mass based on two fundamental units: the metre and the kilogram. Measurement of additional quantities required for science and commerce has necessitated development of additional fundamental and derived units. Numerous other systems based on these two metric units have been used. A unit of time was added to produce the centimetre-gram-second (cgs) system adopted in 1881 by the International Congress of Electricity. About 1900 practical measurements in metric units began to be based on the metre-kilogram-second (MKS) system. In 1935 Prof. Giovanni Giorgi recommended that the MKS system of mechanics be linked with the electromagnetic system of units by adoption of one of the units—ampere, coulomb, ohm, or volt—for the fourth base unit. This recommendation was accepted and in 1950 the ampere, the unit of electric current, was established as a base unit to form the MKSA system.

A2.4 The 10th CGPM in 1954 adopted a rationalized and coherent system of units based on the four MKSA units, plus the degree Kelvin as the unit of temperature and the candela as the unit of luminous intensity. The 11th CGPM in 1960 formally gave it the full title, International System of Units, for which the abbreviation is "SI" in all languages. Thirty-six countries, including the United States, participated in this 1960 conference. The 12th CGPM in 1964 made some refinements, and the 13th CGPM in 1967 redefined the second, renamed the unit of temperature as the kelvin (K), and revised the definition of the candela. The 14th CGPM in 1971 added a seventh base unit, the mole, and approved the pascal (Pa) as a special name for the SI unit of pressure or stress, the newton per square metre, and the siemens (S) as a special name for the unit of electrical conductance, the reciprocal ohm (mho) or the ampere per volt.

A2.5 SI is a rationalized selection of units from the metric system which individually are not new. It includes 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, symbols assigned to each, and, in some cases, given names, as for example, the newton (N).

A2.6 The great advantage of SI is that there is one and only one unit for each physical quantity—the metre 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 such as $v = dl/dt$ (velocity), $a = dv/dt$ (acceleration), $F = ma$ (force), $W = Fl$ (work or energy), $P = W/t$ (power). Some of these units have only generic names such as metre per second for velocity: others have special names such as newton (N) for force, joule (J) for work or energy, watt (W) for power. The SI units for force, energy, and power are the same regardless of whether the process is mechanical, electrical, chemi-

cal, or nuclear. A force of 1 newton applied for a distance of 1 metre can produce 1 joule of heat, which is identical with what 1 watt of electric power can produce in 1 second.

A2.7 Corresponding to the advantages of SI, which result from the use of a unique unit for each physical quantity, are the advantages which result from the use of a unique and well-defined set of symbols and abbreviations. Such symbols and abbreviations 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).

A2.8 Another advantage of SI is its retention of the decimal relation between multiples and submultiples of the base units for each physical quantity—not that there is anything inherently superior in a number system to the base 10 but that SI conforms to the system of Arabic numericals. Prefixes are established for designating multiple and submultiple units from "tera" (10^{12}) down to "atto" (10^{-18}) for convenience in writing and talking.

A2.9 Another major advantage of SI is its coherence. A system of units is coherent if the product or quotient of any two unit quantities in the system is a unit of the resulting quantity. For example, in any coherent system, unit area results when unit length is multipled by unit length, unit velocity when unit length is divided by unit time, and unit force when unit mass is multiplied by unit acceleration. Thus, in a coherent system in which the foot is a unit of length, the square foot is the unit of area (but the acre is not). Similarly in a coherent system in which the foot, the pound, and the second are units of length, mass, and time, the unit of force is the poundal (and not the pound-weight or the pound-force).

A2.10 Whatever the system of units, whether it be coherent or noncoherent, magnitudes of some physical quantities must be arbitrarily selected and declared to have unit value. These magnitudes form a set of standards and are called base units. All other units are derived units related to the base units by definition. The seven base SI units are each very accurately defined in terms of physical measurements that can be made in a laboratory, except the kilogram, which is a particular mass preserved by the International Bureau of Weights and Measures.

A2.11 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. Examples of such units are the bar, a unit of pressure, approximately equivalent to one atmosphere and equal exactly to 100 kilonewtons per square metre. It is employed extensively by meteorologists. Another such unit is the gal equal exactly to an acceleration of 0.01 metre per second squared. It is used in geodetic work. These, however, are not consistent units, that is to say, equations involving both these units and SI units cannot be written without a factor of proportionality even though the factor of proportionality is a simple multiple of 10.

A2.11.1 Originally (1795) the litre was intended to be identical with the cubic decimetre. The Third General Conference on Weights and Measures, meeting in 1901, decided to define the litre as the volume occupied by the mass of one kilogram of pure water at its maximum density under normal atmospheric pressure. Careful determinations subsequently established the litre so defined as being equivalent to 1.000028 dm^3. In 1964 the General Conference on Weights and Measures withdrew this definition of the litre, and declared that the word "litre" was a special name for the cubic decimetre. Thus its use is permitted in SI, but is discouraged, since it creates two units for the same quantity, and its use in precision measurements might conflict with measurements recorded under the old definition.

A2.12 Authorized translations of the original French definitions of the seven base and two supplementary units of the International System are given in the following paragraphs:

A2.12.1 *metre*—The metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom. (adopted at 11th CGPM 1960)

A2.12.2 *kilogram*—The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram. (adopted at 1st and 3rd CGPM 1889 and 1901)

A2.12.3 *second*—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.[8] (adopted at 13th CGPM 1967)

A2.12.4 *ampere*—The ámpere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross section, and placed one metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length. (adopted at 9th CGPM 1948)

A2.12.5 *kelvin*—The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.[9] (Footnote on following page) (adopted at 13th CGPM 1967)

A2.12.6 *mole*—The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12.

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.

A2.12.7 *candela*—The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of a blackbody at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre. (adopted at 13th CGPM 1967)

A2.12.8 *radian*—The unit of measure of a plane angle with its vertex at the center of a circle and subtended by an arc equal in length to the radius. (adopted at 11th CGPM 1960)

A2.12.9 *steradian*—The unit of measure of a solid angle with its vertex at the center of a sphere and enclosing an area of the spherical surface equal to that of a square with sides equal in length to the radius. (adopted at 11th CGPM 1960)

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[8] This definition supersedes the ephemeris second as the unit of time.

A2.13 *Definitions of Derived Units of the International System Having Special Names:*

Physical Quantity	Unit and Definition
A2.13.1 Electric capacitance	The *farad* is the capacitance of a capacitor between the plates of which there appears a difference of potential of one volt when it is charged by a quantity of electricity equal to one coulomb.
A2.13.2 Electrical conductance	The *siemens* is the electrical conductance of a conductor in which a current of one ampere is produced by an electric potential difference of one volt.
A2.13.3 Electric inductance	The *henry* is the inductance of a closed circuit in which an electromotive force of one volt is produced when the electric current in the circuit varies uniformly at a rate of one ampere per second.
A2.13.4 Electric potential difference (electromotive force)	The *volt* (unit of electric potential difference and electromotive force) is the difference of electric potential between two points of a conductor carrying a constant current of one ampere, when the power dissipated between these points is equal to one watt.
A2.13.5 Electric resistance	The *ohm* is the electric resistance between two points of a conductor when a constant difference of potential of one volt, applied between these two points, produces in this conductor a current of one ampere, this conductor not being the source of any electromotive force.
A2.13.6 Energy	The *joule* is the work done when the point of application of a force of one newton is displaced a distance of one metre in the direction of the force.
A2.13.7 Force	The *newton* is that force which, when applied to a body having a mass of one kilogram gives it an acceleration of one metre per second per second.
A2.13.8 Frequency	The *hertz* is a frequency of one cycle per second.
A2.13.9 Illuminance	The *lux* is the illuminance produced by a luminous flux of one lumen uniformly distributed over a surface of one square metre.
A2.13.10 Luminous flux	The *lumen* is the luminous flux emitted in a solid angle of one steradian by a point source having a uniform intensity of one candela.
A2.13.11 Magnetic flux	The *weber* is the magnetic flux which, linking a circuit of one turn, produces in it an electromotive force of one volt as it is reduced to zero at a uniform rate in one second.
A2.13.12 Magnetic flux density	The *tesla* is the magnetic flux density given by a magnetic flux of one weber per square metre.
A2.13.13 Power	The *watt* is the power which gives rise to the production of energy at the rate of one joule per second.
A2.13.14 Pressure or stress	The *pascal* is the pressure or stress of one newton per square metre.
A2.13.15 Quantity of electricity	The *coulomb* is the quantity of electricity transported in one second by a current of one ampere.

A3. CONVERSION FACTORS[10]

A3.1 *General*—The following tables of conversion factors are intended to serve two purposes:

A3.1.1 To express the definitions of miscellaneous units of measure as exact numerical multiples

[9] The International Practical Kelvin Temperature Scale of 1968 and the International Practical Celsius Temperature Scale of 1968 are defined by a set of interpolation equations based on the following reference temperatures[a]:

	K	°C
Hydrogen, solid-liquid-gas equilibrium	13.81	−259.34
Hydrogen, liquid-gas equilibrium at 33 330.6 Pa (25/76 standard atmosphere)	17.042	−256.108
Hydrogen, liquid-gas equilibrium	20.28	−252.87
Neon, liquid-gas equilibrium	27.102	−246.048
Oxygen, solid-liquid-gas equilibrium	54.361	−218.789
Oxygen, liquid-gas equilibrium	90.188	−182.962
Water, solid-liquid-gas equilibrium	273.16	0.01
Water, liquid-gas equilibrium	373.15	100.00
Zinc, solid-liquid equilibrium	692.73	419.58
Silver, solid-liquid equilibrium	1235.08	961.93
Gold, solid-liquid equilibrium	1337.58	1064.43

[a] Except for the triple points and one equilibrium hydrogen point (17.042 K) the assigned values of temperature are for equilibrium states at a pressure

$$p_0 = 1 \text{ standard atmosphere (101 325 Pa).}$$

In this scale the degree Celsius and the kelvin are identical, and are related by an exact difference of 273.15 degrees. It is seldom necessary to recognize the differences between the thermodynamic and practical scales, but the General Conference of Weights and Measures in 1960 established the following quantity symbols for use if desired:

Thermodynamic temperature:	kelvins	T
	degrees Celsius	t
Practical temperature:	kelvins	T_{int}
	degrees Celsius	t_{int}

[10] Based on E. A. Mechtly (Ref 20).

of coherent "metric" units. Relationships that are exact in terms of the base unit are followed by an asterisk. Relationships that are not followed by an asterisk are either the results of physical measurements, or are only approximate.

A3.1.2 To provide multiplying factors for converting expressions of measurements given by numbers and miscellaneous units to corresponding new numbers and metric units.

A3.2 *Notation:*

A3.2.1 Conversion factors are presented for ready adaptation to computer readout and electronic data transmission. The factors are written as a number greater than one and less than ten with six or less decimal places. This number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which 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.

A3.2.2 An asterisk (*) after the sixth decimal place indicates that the conversion factor is exact and that all subsequent digits are zero. All other conversion factors have been rounded to the figures given in accordance with 4.4.

A3.3 *Organization:*

A3.3.1 The conversion factors are listed in two ways—alphabetically and classified by physical quantity. Both lists contain those units which have specific names and compounded units derived from these specific units. The classified list contains the more frequently used units for each physical quantity.[11]

A3.3.2 The conversion factors for other compounded units can easily be generated from numbers given in the alphabetical list by the well-known rules for manipulating units. These rules, being adequately discussed in many science and engineering textbooks, are not repeated here.

ALPHABETICAL LIST OF UNITS

(Symbols of SI units given in parentheses)

To convert from	to	Multiply by
abampere	ampere (A)	1.000 000*E+01
abcoulomb	coulomb (C)	1.000 000*E+01
abfarad	farad (F)	1.000 000*E+09
abhenry	henry (H)	1.000 000*E−09
abmho	siemens (S)	1.000 000*E+09
abohm	ohm (Ω)	1.000 000*E−09
abvolt	volt (V)	1.000 000*E−08
acre-foot (U.S. survey)[12]	metre^3 (m^3)	1.233 489 E+03
acre (U.S. survey)[12]	metre^2 (m^2)	4.046 873 E+03
ampere, international U.S. ($A_{INT\text{-}US}$)[13]	ampere (A)	9.998 43 E−01
ampere, U.S. legal 1948 ($A_{US\text{-}48}$)	ampere (A)	1.000 008 E+00
ampere-hour	coulomb (C)	3.600 000*E+03
angstrom	metre (m)	1.000 000*E−10
are	metre^2 (m^2)	1.000 000*E+02
astronomical unit	metre (m)	1.495 98 E+11
atmosphere (normal)	pascal (Pa)	1.013 25 E+05
atmosphere (technical = 1 kgf/cm^2)	pascal (Pa)	9.806 650*E+04
bar	pascal (Pa)	1.000 000*E+05

[11] Also available from Headquarters is a Conversion Slide Rule (Order No. 12-503800-00) providing some of the most frequently used conversions.

[12] 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 (one foot equals 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 metre 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.

[13] In 1948 a new international agreement was reached on absolute electrical units, which changed the value of the volt used in this country by about 300 parts per million. Again in 1969 a new base of reference was internationally adopted making a further change of 8.4 parts per million. These changes (and also changes in ampere, joule, watt, coulomb) require careful terminology and conversion factors for exact use of old information. Terms used in this guide are:

volt as used prior to January 1948—volt, international U.S. ($V_{INT\text{-}US}$)

volt as used between January 1948 and January 1969—volt, U.S. legal 1948 ($V_{US\text{-}48}$)

volt as used since January 1969—volt (V)

Identical treatment is given the ampere, coulomb, watt, and joule. Since the henry, farad, and ohm were not changed in 1969, only conversions as listed first above are shown.

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To convert from	to	Multiply by
barn	metre² (m²)	1.000 000*E−28
barrel (for petroleum, 42 gal)	metre³ (m³)	1.589 873 E−01
board foot	metre³ (m³)	2.359 737 E−03
British thermal unit (International Table)[14]	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 (thermochemical)/foot²-second	watt/metre² (W/m²)	1.134 893 E+04
Btu (thermochemical)/foot²-minute	watt/metre² (W/m²)	1.891 489 E+02
Btu (thermochemical)/foot²-hour	watt/metre² (W/m²)	3.152 481 E+00
Btu (thermochemical)/inch²-second	watt/metre² (W/m²)	1.634 246 E+06
Btu (thermochemical)·in./s·ft²·°F (*k*, thermal conductivity)	watt/metre-kelvin (W/m·K)	5.188 732 E+02
Btu (International Table)·in./s·ft²·°F (*k*, thermal conductivity)	watt/metre-kelvin (W/m·K)	5.192 204 E+02
Btu (thermochemical)·in./h·ft²·°F (*k*, thermal conductivity)	watt/metre-kelvin (W/m·K)	1.441 314 E−01
Btu (International Table)·in./h·ft²·°F (*k*, thermal conductivity)	watt/metre-kelvin (W/m·K)	1.442 279 E−01
Btu (International Table)/ft²	joule/metre² (J/m²)	1.135 653 E+04
Btu (thermochemical)/ft²	joule/metre² (J/m²)	1.134 893 E+04
Btu (International Table)/h·ft²·°F (*C*, thermal conductance)	watt/metre²-kelvin (W/m²·K)	5.678 263 E+00
Btu (thermochemical)/h·ft²·°F (*C*, thermal conductance)	watt/metre²-kelvin (W/m²·K)	5.674 466 E+00
Btu (International Table)/pound-mass	joule/kilogram (J/kg)	2.326 000*E+03
Btu (thermochemical)/pound-mass	joule/kilogram (J/kg)	2.324 444 E+03
Btu (International Table)/lbm·°F (*c*, heat capacity)	joule/kilogram-kelvin (J/kg·K)	4.186 800*E+03
Btu (thermochemical)/lbm·°F (*c*, heat capacity)	joule/kilogram-kelvin (J/kg·K)	4.184 000 E+03
Btu (International Table)/s·ft²·°F	watt/metre²-kelvin (W/m²·K)	2.044 175 E+04
Btu (thermochemical)/s·ft²·°F	watt/metre²-kelvin (W/m²·K)	2.042 808 E+04
Btu (International Table)/hour	watt (W)	2.930 711 E−01
Btu (thermochemical)/second	watt (W)	1.054 350 E+03
Btu (thermochemical)/minute	watt (W)	1.757 250 E+01
Btu (thermochemical)/hour	watt (W)	2.928 751 E−01
bushel (U.S.)	metre (m³)	3.523 907 E−02
caliber (inch)	metre (m)	2.540 000*E−02
calorie (International Table)	joule (J)	4.186 800*E+00
calorie (mean)	joule (J)	4.190 02 E+00
calorie (thermochemical)	joule (J)	4.184 000*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)	4.186 800*E+03
calorie (kilogram, mean)	joule (J)	4.190 02 E+03
calorie (kilogram, thermochemical)	joule (J)	4.184 000*E+03
calorie (thermochemical)/centimetre²-minute	watt/metre² (W/m²)	6.973 333 E+02
cal (thermochemical)/cm²	joule/metre² (J/m²)	4.184 000*E+04
cal (thermochemical)/cm²·s	watt/metre² (W/m²)	4.184 000*E+04
cal (thermochemical)/cm·s·°C	watt/metre-kelvin (W/m·K)	4.184 000*E+02
cal (International Table)/g	joule/kilogram (J/kg)	4.186 800*E+03
cal (International Table)/g·°C	joule/kilogram-kelvin (J/kg·K)	4.186 800*E+03
cal (thermochemical)/g	joule/kilogram (J/kg)	4.184 000*E+03
cal (thermochemical)/g·°C	joule/kilogram-kelvin (J/kg·K)	4.184 000*E+03
calorie (thermochemical)/second	watt (W)	4.184 000*E+00
calorie (thermochemical)/minute	watt (W)	6.973 333 E−02
carat (metric)	kilogram (kg)	2.000 000*E−04
centimetre of mercury (0°C)	pascal (Pa)	1.333 22 E+03

[14] 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.

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To convert from	to	Multiply by
centimetre of water (4°C)	pascal (Pa)	9.806 38 E+01
centipoise	pascal-second (Pa·s)	1.000 000*E−03
centistokes	metre²/second (m²/s)	1.000 000*E−06
circular mil	metre² (m²)	5.067 075 E−10
clo	kelvin-metre²/watt (K·m²/W)	2.003 712 E−01
coulomb, international U.S. (C_{INT-US})[13]	coulomb (C)	9.998 43 E−01
coulomb, U.S. legal 1948 (C_{US-48})	coulomb (C)	1.000 008 E+00
cup	metre³ (m³)	2.365 882 E−04
curie	disintegration/second	3.700 000*E+10
day (mean solar)	second (s)	8.640 000 E+04
day (sidereal)	second (s)	8.616 409 E+04
decibar	pascal (Pa)	1.000 000*E+04
degree (angle)	radian (rad)	1.745 329 E−02
degree Celsius	kelvin (K)	$t_K = t°_C + 273.15$
degree centigrade	see 3.4.3	
degree Fahrenheit	degree Celsius	$t°_C = (t°_F - 32)/1.8$
degree Fahrenheit	kelvin (K)	$t_K = (t°_F + 459.67)/1.8$
deg F·h·ft²/Btu (thermochemical) (*R*, thermal resistance)	kelvin-metre²/watt (K·m²/W)	1.762 280 E−01
deg F·h·ft²/Btu (International Table) (*R*, thermal resistance)	kelvin-metre²/watt (K·m²/W)	1.761 102 E−01
degree Rankine	kelvin (K)	$t_K = t°_R/1.8$
dyne	newton (N)	1.000 000*E−05
dyne-centimetre	newton-metre (N·m)	1.000 000*E−07
dyne/centimetre²	pascal (Pa)	1.000 000*E−01
electron volt	joule (J)	1.602 19 E−19
EMU of capacitance	farad (F)	1.000 000*E+09
EMU of current	ampere (A)	1.000 000*E+01
EMU of electric potential	volt (V)	1.000 000*E−08
EMU of inductance	henry (H)	1.000 000*E−09
EMU of resistance	ohm (Ω)	1.000 000*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)	1.000 000*E−07
erg/centimetre²-second	watt/metre² (W/m²)	1.000 000*E−03
erg/second	watt (W)	1.000 000*E−07
farad, international U.S. (F_{INT-US})	farad (F)	9.995 05 E−01
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 (U.S. survey)[12]	metre (m)	1.828 804 E+00
fermi (femtometer)	metre (m)	1.000 000*E−15
fluid ounce (U.S.)	metre³ (m³)	2.957 353 E−05
foot	metre (m)	3.048 000*E−01
foot (U.S. survey)[12]	metre (m)	3.048 006 E−01
foot³/minute	metre³/second (m³/s)	4.719 474 E−04
foot³/second	metre³/second (m³/s)	2.831 685 E−02
foot³ (volume and section modulus)	metre³ (m³)	2.831 685 E−02
foot²	metre² (m²)	9.290 304*E−02
foot⁴ (moment of section) (see footnote 15)	metre⁴ (m⁴)	8.630 975 E−03
foot/hour	metre/second (m/s)	8.466 667 E−05
foot/minute	metre/second (m/s)	5.080 000*E−03
foot/second	metre/second (m/s)	3.048 000*E−01
foot²/second	metre²/second (m²/s)	9.290 304*E−02
foot of water (39.2°F)	pascal (Pa)	2.988 98 E+03
footcandle	lumen/metre² (lm/m²)	1.076 391 E+01
footcandle	lux (lx)	1.076 391 E+01
footlambert	candela/metre² (cd/m²)	3.426 259 E+00
foot-pound-force	joule (J)	1.355 818 E+00
foot-pound-force/hour	watt (W)	3.766 161 E−04
foot-pound-force/minute	watt (W)	2.259 697 E−02

[15] This is sometimes called the moment of inertia of a plane section about a specified axis.

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To convert from	to	Multiply by
foot-pound-force/second	watt (W)	1.355 818 E+00
foot-poundal	joule (J)	4.214 011 E−02
ft^2/h (thermal diffusivity)	$metre^2/second$ (m^2/s)	2.580 640*E−05
$foot/second^2$	$metre/second^2$ (m/s^2)	3.048 000*E−01
free fall, standard	$metre/second^2$ (m/s^2)	9.806 650*E+00
gal	$metre/second^2$ (m/s^2)	1.000 000*E−02
gallon (Canadian liquid)	$metre^3$ (m^3)	4.546 090 E−03
gallon (U.K. liquid)	$metre^3$ (m^3)	4.546 092 E−03
gallon (U.S. dry)	$metre^3$ (m^3)	4.404 884 E−03
gallon (U.S. liquid)	$metre^3$ (m^3)	3.785 412 E−03
gallon (U.S. liquid)/day	$metre^3/second$ (m^3/s)	4.381 264 E−08
gallon (U.S. liquid)/minute	$metre^3/second$ (m^3/s)	6.309 020 E−05
gamma	tesla (T)	1.000 000*E−09
gauss	tesla (T)	1.000 000*E−04
gilbert	ampere-turn	7.957 747 E−01
gill (U.K.)	$metre^3$ (m^3)	1.420 654 E−04
gill (U.S.)	$metre^3$ (m^3)	1.182 941 E−04
grad	degree (angular)	9.000 000*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)/gallon (U.S. liquid)	$kilogram/metre^3$ (kg/m^3)	1.711 806 E−02
gram	kilogram (kg)	1.000 000*E−03
$gram/centimetre^3$	$kilogram/metre^3$ (kg/m^3)	1.000 000*E+03
$gram\text{-}force/centimetre^2$	pascal (Pa)	9.806 650*E+01
hectare	$metre^2$ (m^2)	1.000 000*E+04
henry, international U.S. ($H_{INT\text{-}US}$)	henry (H)	1.000 495 E+00
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)	7.460 000*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	metre (m)	2.540 000*E−02
$inch^2$	$metre^2$ (m^2)	6.451 600*E−04
$inch^3$ (volume and section modulus)	$metre^3$ (m^3)	1.638 706 E−05
$inch^3/minute$	$metre^3/second$ (m^3/s)	2.731 177 E−07
$inch^4$ (moment of section) (see footnote 15)	$metre^4$ (m^4)	4.162 314 E−07
inch/second	metre/second (m/s)	2.540 000*E−02
inch of mercury (32°F)	pascal (Pa)	3.386 389 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
$inch/second^2$	$metre/second^2$ (m/s^2)	2.540 000*E−02
joule, international U.S. ($J_{INT\text{-}US}$)[15]	joule (J)	1.000 182 E+00
joule, U.S. legal 1948 ($J_{US\text{-}48}$)	joule (J)	1.000 017 E+00
kayser	1/metre (1/m)	1.000 000*E+02
kelvin	degree Celsius	$t_C = t_K - 273.15$
kilocalorie (International Table)	joule (J)	4.186 800*E+03
kilocalorie (mean)	joule (J)	4.190 02 E+03
kilocalorie (thermochemical)	joule (J)	4.184 000*E+03
kilocalorie (thermochemical)/minute	watt (W)	6.973 333 E+01
kilocalorie (thermochemical)/second	watt (W)	4.184 000*E+03
kilogram-force (kgf)	newton (N)	9.806 650*E+00
kilogram-force-metre	newton-metre (N·m)	9.806 650*E+00
$kilogram\text{-}force\text{-}second^2/metre$ (mass)	kilogram (kg)	9.806 650*E+00
$kilogram\text{-}force/centimetre^2$	pascal (Pa)	9.806 650*E+04
$kilogram\text{-}force/metre^2$	pascal (Pa)	9.806 650*E+00
$kilogram\text{-}force/millimetre^2$	pascal (Pa)	9.806 650*E+06
kilogram-mass	kilogram (kg)	1.000 000*E+00
kilometre/hour	metre/second (m/s)	2.777 778 E−01
kilopond	newton (N)	9.806 650*E+00
kilowatt-hour	joule (J)	3.600 000*E+06

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To convert from	to	Multiply by
kilowatt-hour, international U.S. (kWh_{INT-US})[18]	joule (J)	3.600 655 E+06
kilowatt-hour, U.S. legal 1948 (kWh_{US-48})	joule (J)	3.600 061 E+06
kip (1000 lbf)	newton (N)	4.448 222 E+03
kip/inch^2 (ksi)	pascal (Pa)	6.894 757 E+06
knot (international)	metre/second (m/s)	5.144 444 E−01
lambert	candela/metre^2 (cd/m^2)	$1/\pi$* E+04
lambert	candela/metre^2 (cd/m^2)	3.183 099 E+03
langley	joule/metre^2 (J/m^2)	4.184 000*E+04
league, nautical (international and U.S.	metre (m)	5.556 000*E+03
league (U.S. survey)[12]	metre (m)	4.828 042 E+03
league, nautical (U.K.)	metre (m)	5.559 552*E+03
light year	metre (m)	9.460 55 E+15
litre[18]	metre^3 (m^3)	1.000 000*E−03
lux	lumen/metre^2 (lm/m^2)	1.000 000*E+00
maxwell	weber (Wb)	1.000 000*E−08
mho	siemens (S)	1.000 000*E+00
microinch	metre (m)	2.540 000*E−08
micron	metre (m)	1.000 000*E−06
mil	metre (m)	2.540 000*E−05
mile, nautical (international and U.S.)	metre (m)	1.852 000*E+03
mile, nautical (U.K.)	metre (m)	1.853 184*E+03
mile (international)	metre (m)	1.609 344*E+03
mile (U.S. survey)[12]	metre (m)	1.609 347 E+03
mile^2 (international)	metre^2 (m^2)	2.589 988 E+06
mile^2 (U.S. survey)[12]	metre^2 (m^2)	2.589 998 E+06
mile/hour (international)	metre/second (m/s)	4.470 400*E−01
mile/minute (international)	metre/second (m/s)	2.682 240*E+01
mile/second (international)	metre/second (m/s)	1.609 344*E+03
mile/hour (international)	kilometre/hour	1.609 344*E+00
millibar	pascal (Pa)	1.000 000*E+02
millimetre of mercury (0 °C)	pascal (Pa)	1.333 224 E+02
minute (angle)	radian (rad)	2.908 882 E−04
minute (mean solar)	second (s)	6.000 000 E+01
minute (sidereal)	second (s)	5.983 617 E+01
month (mean calendar)	second (s)	2.268 000 E+06
oersted	ampere/metre (A/m)	7.957 747 E+01
ohm, international U.S. (Ω_{INT-US})	ohm (Ω)	1.000 495 E+00
ohm-centimetre	ohm-metre (Ω·m)	1.000 000*E−02
ounce-force (avoirdupois)	newton (N)	2.780 139 E−01
ounce-force-inch	newton-metre (N·m)	7.061 552 E−03
ounce-mass (avoirdupois)	kilogram (kg)	2.834 952 E−02
ounce-mass (troy or apothecary)	kilogram (kg)	3.110 348 E−02
ounce-mass/yard^2	kilogram/metre^2 (kg/m^2)	3.390 575 E−02
ounce (avoirdupois)/gallon (U.K. liquid)	kilogram/metre^3 (kg/m^3)	6.236 021 E+00
ounce (avoirdupois)/gallon (U.S. liquid)	kilogram/metre^3 (kg/m^3)	7.489 152 E+00
ounce (avoirdupois) (mass)/inch^3	kilogram/metre^3 (kg/m^3)	1.729 994 E+03
ounce (U.K. fluid)	metre^3 (m^3)	2.841 307 E−05
ounce (U.S. fluid)	metre^3 (m^3)	2.957 353 E−05
parsec	metre (m)	3.083 74 E+16
peck (U.S.)	metre^3 (m^3)	8.809 768 E−03
pennyweight	kilogram (kg)	1.555 174 E−03
perm (0°C)	kilogram/pascal-second-metre^2 (kg/Pa·s·m^2)	5.721 35 E−11
perm (23°C)	kilogram/pascal-second-metre^2 (kg/Pa·s·m^2)	5.745 25 E−11
perm-inch (0°C)	kilogram/pascal-second-metre (kg/Pa·s·m)	1.453 22 E−12

[18] In 1964 the General Conference on Weights and Measures adopted the name litre as a special name for the cubic decimetre. Prior to this decision the litre differed slightly (previous value, 1.000028 dm^3) and in expression of precision volume measurement this fact must be kept in mind.

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To convert from	to	Multiply by
perm-inch (23°C)	kilogram/pascal-second-metre (kg/Pa·s·m)	1.459 29 E−12
phot	lumen/metre² (lm/m²)	1.000 000*E+04
pica (printer's)	metre (m)	4.217 518 E−03
pint (U.S. dry)	metre³ (m³)	5.506 105 E−04
pint (U.S. liquid)	metre³ (m³)	4.731 765 E−04
point (printer's)	metre	3.514 598*E−04
poise (absolute viscosity)	pascal-second (Pa·s)	1.000 000*E−01
poundal	newton (N)	1.382 550 E−01
poundal/foot²	pascal (Pa)	1.488 164 E+00
poundal-second/foot²	pascal-second (Pa·s)	1.488 164 E+00
pound-force (lbf avoirdupois)[17]	newton (N)	4.448 222 E+00
pound-force-inch	newton-metre (N·m)	1.129 848 E−01
pound-force-foot	newton-metre (N·m)	1.355 818 E+00
pound-force-foot/inch	newton-metre/metre (N·m/m)	5.337 866 E+01
pound-force-inch/inch	newton-metre/metre (N·m/m)	4.448 222 E+00
pound-force/inch	newton/metre (N/m)	1.751 268 E+02
pound-force/foot	newton/metre (N/m)	1.459 390 E+01
pound-force/foot²	pascal (Pa)	4.788 026 E+01
pound-force/inch² (psi)	pascal (Pa)	6.894 757 E+03
pound-force-second/foot²	pascal-second (Pa·s)	4.788 026 E+01
pound-mass (lbm avoirdupois)[18]	kilogram (kg)	4.535 924 E−01
pound-mass (troy or apothecary)	kilogram (kg)	3.732 417 E−01
pound-mass-foot² (moment of inertia)	kilogram-metre² (kg·m²)	4.214 011 E−02
pound-mass-inch² (moment of inertia)	kilogram-metre² (kg·m²)	2.926 397 E−04
pound-mass/foot²	kilogram/metre² (kg/m²)	4.882 428 E+00
pound-mass/second	kilogram/second (kg/s)	4.535 924 E−01
pound-mass/minute	kilogram/second (kg/s)	7.559 873 E−03
pound-mass/foot³	kilogram/metre³ (kg/m³)	1.601 846 E+01
pound-mass/inch³	kilogram/metre³ (kg/m³)	2.767 990 E+04
pound-mass/gallon (U.K. liquid)	kilogram/metre³ (kg/m³)	9.977 633 E+01
pound-mass/gallon (U.S. liquid)	kilogram/metre³ (kg/m³)	1.198 264 E+02
pound-mass/foot-second	pascal-second (Pa·s)	1.488 164 E+00
quart (U.S. dry)	metre³ (m³)	1.101 221 E−03
quart (U.S. liquid)	metre³ (m³)	9.463 529 E−04
rad (radiation dose absorbed)	joule/kilogram (J/kg)	1.000 000*E−02
rhe	metre²/newton-second (m²/N·s)	1.000 000*E+01
rod (U.S. survey)[12]	metre (m)	5.029 210 E+00
roentgen	coulomb/kilogram (C/kg)	2.579 760*E−04
second (angle)	radian (rad)	4.848 137 E−06
second (sidereal)	second (s)	9.972 696 E−01
section (U.S. survey)[12]	metre² (m²)	2.589 998 E+06
shake	second (s)	1.000 000*E−08
slug	kilogram (kg)	1.459 390 E+01
slug/foot³	kilogram/metre³ (kg/m³)	5.153 788 E+02
slug/foot-second	pascal-second (Pa·s)	4.788 026 E+01
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	metre³ (m³)	1.000 000*E+00
stilb	candela/metre² (cd/m²)	1.000 000*E+04
stokes (kinematic viscosity)	metre²/second (m²/s)	1.000 000*E−04
tablespoon	metre³ (m³)	1.478 676 E−05
teaspoon	metre³ (m³)	4.928 922 E−06
tex	kilogram/metre (kg/m)	1.000 000*E−06
ton (assay)	kilogram (kg)	2.916 667 E−02
ton (long, 2240 lbm)	kilogram (kg)	1.016 047 E+03
ton (metric)	kilogram (kg)	1.000 000*E+03

[17] The exact conversion factor is 4.448 221 615 260 5*E+00.
[18] The exact conversion factor is 4.535 923 7*E−01.

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To convert from	to	Multiply by
ton (nuclear equivalent of TNT)	joule (J)	4.20 E+09
ton (register)	metre^3 (m^3)	2.831 685 E+00
ton (short, 2000 lbm)	kilogram (kg)	9.071 847 E+02
ton (short, mass)/hour	kilogram/second (kg/s)	2.519 958 E−01
ton (long, mass)/yard^3	kilogram/metre^3 (kg/m^3)	1.328 939 E+03
tonne	kilogram (kg)	1.000 000*E+03
torr (mm Hg, 0°C)	pascal (Pa)	1.333 22 E+02
township (U.S. survey)[12]	metre^2 (m^2)	9.323 994 E+07
unit pole	weber (Wb)	1.256 637 E−07
volt, international U.S. (V_{INT-US})[13]	volt (V)	1.000 338 E+00
volt, U.S. legal 1948 (V_{US-48})	volt (V)	1.000 008 E+00
watt, international U.S. (W_{INT-US})[13]	watt (W)	1.000 182 E+00
watt, U.S. legal 1948 (W_{US-48})	watt (W)	1.000 017 E+00
watt/centimetre^2	watt/metre^2 (W/m^2)	1.000 000*E+04
watt-hour	joule (J)	3.600 000*E+03
watt-second	joule (J)	1.000 000*E+00
yard	metre (m)	9.144 000*E−01
yard^2	metre^2 (m^2)	8.361 274 E−01
yard^3	metre^3 (m^3)	7.645 549 E−01
yard^3/minute	metre^3/second (m^3/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

CLASSIFIED LIST OF UNITS

Acceleration

foot/second^2	metre/second^2 (m/s^2)	3.048 000*E−01
free fall, standard	metre/second^2 (m/s^2)	9.806 650*E+00
gal	metre/second^2 (m/s^2)	1.000 000*E−02
inch/second^2	metre/second^2 (m/s^2)	2.540 000*E−02

Area

acre (U.S. survey)[12]	metre^2 (m^2)	4.046 873 E+03
are	metre^2 (m^2)	1.000 000*E+02
barn	metre^2 (m^2)	1.000 000*E−28
circular mil	metre^2 (m^2)	5.067 075 E−10
foot^2	metre^2 (m^2)	9.290 304*E−02
hectare	metre^2 (m^2)	1.000 000*E+04
inch^2	metre^2 (m^2)	6.451 600*E−04
mile^2 (international)	metre^2 (m^2)	2.589 988 E+06
mile^2 (U.S. survey)[12]	metre^2 (m^2)	2.589 998 E+06
section (U.S. survey)[12]	metre^2 (m^2)	2.589 998 E+06
township (U.S. survey)[12]	metre^2 (m^2)	9.323 994 E+07
yard^2	metre^2 (m^2)	8.361 274 E−01

Bending Moment or Torque

dyne-centimetre	newton-metre (N·m)	1.000 000*E−07
kilogram-force-metre	newton-metre (N·m)	9.806 650*E+00
ounce-force-inch	newton-metre (N·m)	7.061 552 E−03
pound-force-inch	newton-metre (N·m)	1.129 848 E−01
pound-force-foot	newton-metre (N·m)	1.355 818 E+00

(Bending Moment or Torque)/Length

pound-force-foot/inch	newton-metre/metre (N·m/m)	5.337 866 E+01
pound-force-inch/inch	newton-metre/metre (N·m/m)	4.448 222 E+00

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Capacity (See Volume)

Density (See Mass/Volume)

Electricity and Magnetism[19]

To convert from	to	Multiply by
abampere	ampere (A)	1.000 000*E+01
abcoulomb	coulomb (C)	1.000 000*E+01
abfarad	farad (F)	1.000 000*E+09
abhenry	henry (H)	1.000 000*E−09
abmho	siemens (S)	1.000 000*E+09
abohm	ohm (Ω)	1.000 000*E−09
abvolt	volt (V)	1.000 000*E−08
ampere, international U.S. (A_{INT-US})[13]	ampere (A)	9.998 43 E−01
ampere, U.S. legal 1948 (A_{US-48})	ampere (A)	1.000 008 E+00
ampere-hour	coulomb (C)	3.600 000*E+03
coulomb, international U.S. (C_{INT-US})[13]	coulomb (C)	9.998 43 E−01
coulomb, U.S. legal 1948 (C_{US-48})	coulomb (C)	1.000 008 E+00
EMU of capacitance	farad (F)	1.000 000*E+09
EMU of current	ampere (A)	1.000 000*E+01
EMU of electric potential	volt (V)	1.000 000*E−08
EMU of inductance	henry (H)	1.000 000*E−09
EMU of resistance	ohm (Ω)	1.000 000*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
farad, international U.S. (F_{INT-US})	farad (F)	9.995 05 E−01
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
gamma	tesla (T)	1.000 000*E−09
gauss	tesla (T)	1.000 000*E−04
gilbert	ampere-turn	7.957 747 E−01
henry, international U.S. (H_{INT-US})	henry (H)	1.000 495 E+00
maxwell	weber (Wb)	1.000 000*E−08
mho	siemens (S)	1.000 000*E+00
oersted	ampere/metre (A/m)	7.957 747 E+01
ohm, international U.S. (Ω_{INT-US})	ohm (Ω)	1.000 495 E+00
ohm-centimeter	ohm-metre (Ω·m)	1.000 000*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
unit pole	weber (Wb)	1.256 637 E−07
volt, international U.S. (V_{INT-US})[13]	volt (V)	1.000 338 E+00
volt, U.S. legal 1948 (V_{US-48})	volt (V)	1.000 008 E+00

Energy (Includes Work)

British thermal unit (International Table)[14]	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
calorie (International Table)	joule (J)	4.186 800*E+00
calorie (mean)	joule (J)	4.190 02 E+00

[19] ESU means electrostatic cgs unit. EMU means electromagnetic cgs unit.

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To convert from	to	Multiply by
calorie (thermochemical)	joule (J)	4.184 000*E+00
calorie (15°C)	joule (J)	4.185 80 E+00
calorie (20°C)	joule (J)	4.181 90 E+00
calorie (kg, International Table)	joule (J)	4.186 800*E+03
calorie (kg, mean)	joule (J)	4.190 02 E+03
calorie (kg, thermochemical)	joule (J)	4.184 000*E+03
electron volt	joule (J)	1.602 19 E−19
erg	joule (J)	1.000 000*E−07
foot-pound-force	joule (J)	1.355 818 E+00
foot-poundal	joule (J)	4.214 011 E−02
joule, international U.S. (J_{INT-US})[13]	joule (J)	1.000 182 E+00
joule, U.S. legal 1948 (J_{US-48})	joule (J)	1.000 017 E+00
kilocalorie (International Table)	joule (J)	4.186 800*E+03
kilocalorie (mean)	joule (J)	4.190 02 E+03
kilocalorie (thermochemical)	joule (J)	4.184 000*E+03
kilowatt-hour	joule (J)	3.600 000*E+06
kilowatt-hour, international U.S. (kWh_{INT-US})[13]	joule (J)	3.600 655 E+06
kilowatt-hour, U.S. legal 1948 (kWh_{US-48})	joule (J)	3.600 061 E+06
ton (nuclear equivalent of TNT)	joule (J)	4.20 E+09
watt-hour	joule (J)	3.600 000*E+03
watt-second	joule (J)	1.000 000*E+00

Energy/Area Time

Btu (thermochemical)/foot²-second	watt/metre² (W/m²)	1.134 893 E+04
Btu (thermochemical)/foot²-minute	watt/metre² (W/m²)	1.891 489 E+02
Btu (thermochemical)/foot²-hour	watt/metre² (W/m²)	3.152 481 E+00
Btu (thermochemical)/inch²-second	watt/metre² (W/m²)	1.634 246 E+06
calorie (thermochemical)/centimetre²-minute	watt/metre² (W/m²)	6.973 333 E+02
erg/centimetre²-second	watt/metre² (W/m²)	1.000 000*E−03
watt/centimetre²	watt/metre² (W/m²)	1.000 000*E+04

Flow (See Mass/Time or Volume/Time)

Force

dyne	newton (N)	1.000 000*E−05
kilogram-force	newton (N)	9.806 650*E+00
kilopond	newton (N)	9.806 650*E+00
kip	newton (N)	4.448 222 E+03
ounce-force (avoirdupois)	newton (N)	2.780 139 E−01
pound-force (lbf avoirdupois)[17]	newton (N)	4.448 222 E+00
poundal	newton (N)	1.382 550 E−01

Force/Area (See Pressure)

Force/Length

pound-force/inch	newton/metre (N/m)	1.751 268 E+02
pound-force/foot	newton/metre (N/m)	1.459 390 E+01

Heat

Btu (thermochemical)·in./s·ft²·°F (*k*, thermal conductivity)	watt/metre-kelvin (W/m·K)	5.188 732 E+02
Btu (International Table)·in./s·ft²·°F (*k*, thermal conductivity)	watt/metre-kelvin (W/m·K)	5.192 204 E+02
Btu (thermochemical)·in./h·ft²·°F (*k*, thermal conductivity)	watt/metre-kelvin (W/m·K)	1.441 314 E−01

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To convert from	to	Multiply by
Btu (International Table)·in./h·ft²·°F (*k*, thermal conductivity)	watt/metre-kelvin (W/m·K)	1.442 279 E−01
Btu (International Table)/ft²	joule/metre² (J/m²)	1.135 653 E+04
Btu (thermochemical)/ft²	joule/metre² (J/m²)	1.134 893 E+04
Btu (International Table)/h·ft²·°F (*C*, thermal conductance)	watt/metre²-kelvin (W/m²·K)	5.678 263 E+00
Btu (thermochemical)/h·ft²·°F (*C*, thermal conductance)	watt/metre²-kelvin (W/m²·K)	5.674 466 E+00
Btu (International Table)/pound-mass	joule/kilogram (J/kg)	2.326 000*E+03
Btu (thermochemical)/pound-mass	joule/kilogram (J/kg)	2.324 444 E+03
Btu (International Table)/lbm·°F (*c*, heat capacity)	joule/kilogram-kelvin (J/kg·K)	4.186 800*E+03
Btu (thermochemical)/lbm·°F (*c*, heat capacity)	joule/kilogram-kelvin (J/kg·K)	4.184 000 E+03
Btu (International Table)/s·ft²·°F	watt/metre²-kelvin (W/m²·K)	2.044 175 E+04
Btu (thermochemical)/s·ft²·°F	watt/metre²-kelvin (W/m²·K)	2.042 808 E+04
cal (thermochemical)/cm²	joule/metre² (J/m²)	4.184 000*E+04
cal (thermochemical)/cm²·s	watt/metre² (W/m²)	4.184 000*E+04
cal (thermochemical)/cm·s·°C	watt/metre-kelvin (W/m·K)	4.184 000*E+02
cal (International Table)/g	joule/kilogram (J/kg)	4.186 800*E+03
cal (International Table)/g·°C	joule/kilogram-kelvin (J/kg·K)	4.186 800*E+03
cal (thermochemical)/g	joule/kilogram (J/kg)	4.184 000*E+03
cal (thermochemical)/g·°C	joule/kilogram-kelvin (J/kg·K)	4.184 000*E+03
clo	kelvin-metre²/watt (K·m²/W)	2.003 712 E−01
deg F·h·ft²/Btu (thermochemical) (*R*, thermal resistance)	kelvin-metre²/watt (K·m²/W)	1.762 280 E−01
deg F·h·ft²/Btu (International Table) (*R*, thermal resistance)	kelvin-metre²/watt (K·m²/W)	1.761 102 E−01
ft²/h (thermal diffusivity)	metre²/second (m²/s)	2.580 640*E−05

Length

angstrom	metre (m)	1.000 000*E−10
astronomical unit	metre (m)	1.495 98 E+11
caliber (inch)	metre (m)	2.540 000*E−02
fathom (U.S. survey)[12]	metre (m)	1.828 804 E+00
fermi (femtometer)	metre (m)	1.000 000*E−15
foot	metre (m)	3.048 000*E−01
foot (U.S. survey)[12]	metre (m)	3.048 006 E−01
inch	metre (m)	2.540 000*E−02
league, nautical (international and U.S.)	metre (m)	5.556 000*E+03
league (U.S. survey)[12]	metre (m)	4.828 042 E+03
league, nautical (U.K.)	metre (m)	5.559 552*E+03
light year	metre (m)	9.460 55 E+15
microinch	metre (m)	2.540 000*E−08
micron	metre (m)	1.000 000*E−06
mil	metre (m)	2.540 000*E−05
mile, nautical (international and U.S.)	metre (m)	1.852 000*E+03
mile, nautical (U.K.)	metre (m)	1.853 184*E+03
mile (international)	metre (m)	1.609 344*E+03
mile (U.S. survey)[12]	metre (m)	1.609 347 E+03
parsec	metre (m)	3.083 74 E+16
pica (printer's)	metre (m)	4.217 518 E−03
point (printer's)	metre (m)	3.514 598*E−04
rod (U.S. survey)[12]	metre (m)	5.029 210 E+00
yard	metre (m)	9.144 000*E−01

Light

footcandle	lumen/metre² (lm/m²)	1.076 391 E+01
footcandle	lux (lx)	1.076 391 E+01

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To convert from	to	Multiply by
footlambert	candela/metre^2 (cd/m^2)	3.426 259 E+00
lux	lumen/metre^2 (lm/m^2)	1.000 000*E+00

Mass

carat (metric)	kilogram (kg)	2.000 000*E−04
grain	kilogram (kg)	6.479 891*E−05
gram	kilogram (kg)	1.000 000*E−03
hundredweight (long)	kilogram (kg)	5.080 235 E+01
hundredweight (short)	kilogram (kg)	4.535 924 E+01
kilogram-force-second^2/metre (mass)	kilogram (kg)	9.806 650*E+00
kilogram-mass	kilogram (kg)	1.000 000*E+00
ounce-mass (avoirdupois)	kilogram (kg)	2.834 952 E−02
ounce-mass (troy or apothecary)	kilogram (kg)	3.110 348 E−02
pennyweight	kilogram (kg)	1.555 174 E−03
pound-mass (lbm avoirdupois)[18]	kilogram (kg)	4.535 924 E−01
pound-mass (troy or apothecary)	kilogram (kg)	3.732 417 E−01
slug	kilogram (kg)	1.459 390 E+01
ton (assay)	kilogram (kg)	2.916 667 E−02
ton (long, 2240 lbm)	kilogram (kg)	1.016 047 E+03
ton (metric)	kilogram (kg)	1.000 000*E+03
ton (short, 2000 lbm)	kilogram (kg)	9.071 847 E+02
tonne	kilogram (kg)	1.000 000*E+03

Mass/Area

ounce-mass/yard^2	kilogram/metre^2 (kg/m^2)	3.390 575 E−02
pound-mass/foot^2	kilogram/metre^2 (kg/m^2)	4.882 428 E+00

Mass/Capacity (See Mass/Volume)

Mass/Length

denier	kilogram/metre (kg/m)	9.000 000*E−06
pound-mass/foot	kilogram/metre (kg/m)	1.488 164 E+00
pound-mass/inch	kilogram/metre (kg/m)	1.785 797 E+01
tex	kilogram/metre (kg/m)	1.000 000*E−06

Mass/Time (Includes Flow)

perm (0°C)	kilogram/pascal-second-metre^2 (kg/Pa·s·m^2)	5.721 35 E−11
perm (23°C)	kilogram/pascal-second-metre^2 (kg/Pa·s·m^2)	5.745 25 E−11
perm-inch (0°C)	kilogram/pascal-second-metre (kg/Pa·s·m)	1.453 22 E−12
perm-inch (23°C)	kilogram/pascal-second-metre (kg/Pa·s·m)	1.459 29 E−12
pound-mass/second	kilogram/second (kg/s)	4.535 924 E−01
pound-mass/minute	kilogram/second (kg/s)	7.559 873 E−03
ton (short, mass)/hour	kilogram/second (kg/s)	2.519 958 E−01

Mass/Volume (Includes Density and Mass Capacity)

grain (lbm avoirdupois/7000)/gallon (U.S. liquid)	kilogram/metre^3 (kg/m^3)	1.711 806 E−02
gram/centimetre^3	kilogram/metre^3 (kg/m^3)	1.000 000*E+03
ounce (avoirdupois)/gallon (U.K. liquid	kilogram/metre^3 (kg/m^3)	6.236 021 E+00

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To convert from	to	Multiply by
ounce (avoirdupois)/gallon (U.S. liquid)	kilogram/metre^3 (kg/m^3)	7.489 152 E+00
ounce (avoirdupois) (mass)/inch^3	kilogram/metre^3 (kg/m^3)	1.729 994 E+03
pound-mass/foot^3	kilogram/metre^3 (kg/m^3)	1.601 846 E+01
pound-mass/inch^3	kilogram/metre^3 (kg/m^3)	2.767 990 E+04
pound-mass/gallon (U.K. liquid)	kilogram/metre^3 (kg/m^3)	9.977 633 E+01
pound-mass/gallon (U.S. liquid)	kilogram/metre^3 (kg/m^3)	1.198 264 E+02
slug/foot^3	kilogram/metre^3 (kg/m^3)	5.153 788 E+02
ton (long, mass)/yard^3	kilogram/metre^3 (kg/m^3)	1.328 939 E+03

Power

Btu (International Table)/hour	watt (W)	2.930 711 E−01
Btu (thermochemical)/second	watt (W)	1.054 350 E+03
Btu (thermochemical)/minute	watt (W)	1.757 250 E+01
Btu (thermochemical)/hour	watt (W)	2.928 751 E−01
calorie (thermochemical)/second	watt (W)	4.184 000*E+00
calorie (thermochemical)/minute	watt (W)	6.973 333 E−02
erg/second	watt (W)	1.000 000*E−07
foot-pound-force/hour	watt (W)	3.766 161 E−04
foot-pound-force/minute	watt (W)	2.259 697 E−02
foot-pound-force/second	watt (W)	1.355 818 E+00
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)	7.460 000*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
kilocalorie (thermochemical)/minute	watt (W)	6.973 333 E+01
kilocalorie (thermochemical)/second	watt (W)	4.184 000*E+03
watt, international U.S. (W_{INT-US})[18]	watt (W)	1.000 182 E+00
watt, U.S. legal 1948 (W_{US-48})	watt (W)	1.000 017 E+00

Pressure or Stress (Force/Area)

atmosphere (normal = 760 torr)	pascal (Pa)	1.013 25 E+05
atmosphere (technical = 1 kgf/cm^2)	pascal (Pa)	9.806 650*E+04
bar	pascal (Pa)	1.000 000*E+05
centimetre of mercury (0°C)	pascal (Pa)	1.333 22 E+03
centimetre of water (4°C)	pascal (Pa)	9.806 38 E+01
decibar	pascal (Pa)	1.000 000*E+04
dyne/centimetre^2	pascal (Pa)	1.000 000*E−01
foot of water (39.2°F)	pascal (Pa)	2.988 98 E+03
gram-force/centimetre^2	pascal (Pa)	9.806 650*E+01
inch of mercury (32°F)	pascal (Pa)	3.386 389 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
kilogram-force/centimetre^2	pascal (Pa)	9.806 650*E+04
kilogram-force/metre^2	pascal (Pa)	9.806 650*E+00
kilogram-force/millimetre^2	pascal (Pa)	9.806 650*E+06
kip/inch^2 (ksi)	pascal (Pa)	6.894 757 E+06
millibar	pascal (Pa)	1.000 000*E+02
millimetre of mercury (0°C)	pascal (Pa)	1.333 224 E+02
poundal/foot^2	pascal (Pa)	1.488 164 E+00
pound-force/foot^2	pascal (Pa)	4.788 026 E+01
pound-force/inch^2 (psi)	pascal (Pa)	6.894 757 E+03
psi	pascal (Pa)	6.894 757 E+03
torr (mm Hg, 0°C)	pascal (Pa)	1.333 22 E+02

Speed (See Velocity)

Stress (See Pressure)

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Temperature

To convert from	to	Multiply by
degree Celsius	kelvin (K)	$t_K = t°_C + 273.15$
degree Fahrenheit	kelvin (K)	$t_K = (t°_F + 459.67)/1.8$
degree Rankine	kelvin (K)	$t_K = t°_R/1.8$
degree Fahrenheit	degree Celsius	$t°_C = (t°_F - 32)/1.8$
kelvin	degree Celsius	$t°_C = t_K - 273.15$

Time

day (mean solar)	second (s)	8.640 000 E+04
day (sidereal)	second (s)	8.616 409 E+04
hour (mean solar)	second (s)	3.600 000 E+03
hour (sidereal)	second (s)	3.590 170 E+03
minute (mean solar)	second (s)	6.000 000 E+01
minute (sidereal)	second (s)	5.983 617 E+01
month (mean calendar)	second (s)	2.628 000 E+06
second (sidereal)	second (s)	9.972 696 E−01
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

Torque (See Bending Moment)

Velocity (Includes Speed)

foot/hour	metre/second (m/s)	8.466 667 E−05
foot/minute	metre/second (m/s)	5.080 000*E−03
foot/second	metre/second (m/s)	3.048 000*E−01
inch/second	metre/second (m/s)	2.540 000*E−02
kilometre/hour	metre/second (m/s)	2.777 778 E−01
knot (international)	metre/second (m/s)	5.144 444 E−01
mile/hour (international)	metre/second (m/s)	4.470 400*E−01
mile/minute (international)	metre/second (m/s)	2.682 240*E+01
mile/second (international)	metre/second (m/s)	1.609 344*E+03
mile/hour (international)	kilometre/hour[20]	1.609 344*E+00

Viscosity

centipoise	pascal-second (Pa·s)	1.000 000*E−03
centistokes	metre²/second (m²/s)	1.000 000*E−06
foot²/second	metre²/second (m²/s)	9.290 304*E−02
poise	pascal-second (Pa·s)	1.000 000*E−01
poundal-second/foot²	pascal-second (Pa·s)	1.488 164 E+00
pound-mass/foot-second	pascal-second (Pa·s)	1.488 164 E+00
pound-force-second/foot²	pascal-second (Pa·s)	4.788 026 E+01
rhe	metre²/newton-second (m²/N·s)	1.000 000*E+01
slug/foot-second	pascal-second (Pa·s)	4.788 026 E+01
stokes	metre²/second (m²/s)	1.000 000*E−04

Volume (Includes Capacity)

acre-foot (U.S. survey)[12]	metre³ (m³)	1.233 489 E+03
barrel (oil, 42 gal)	metre³ (m³)	1.589 873 E−01
board foot	metre³ (m³)	2.359 737 E−03
bushel (U.S.)	metre³ (m³)	3.523 907 E−02
cup	metre³ (m³)	2.365 882 E−04
fluid ounce (U.S.)	metre³ (m³)	2.957 353 E−05
foot³	metre³ (m³)	2.831 685 E−02

[20] Although speedometers may read km/h, the correct SI unit is m/s.
[21] The exact conversion factor is 1.638 706 4*E-05.

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To convert from	to	Multiply by
gallon (Canadian liquid)	metre^3 (m^3)	4.546 090 E−03
gallon (U.K. liquid)	metre^3 (m^3)	4.546 092 E−03
gallon (U.S. dry)	metre^3 (m^3)	4.404 884 E−03
gallon (U.S. liquid)	metre^3 (m^3)	3.785 412 E−03
gill (U.K.)	metre^3 (m^3)	1.420 654 E−04
gill (U.S.)	metre^3 (m^3)	1.182 941 E−04
inch^3(see footnote 21)	metre^3 (m^3)	1.638 706 E−05
litre (see footnote 16)	metre^3 (m^3)	1.000 000*E−03
ounce (U.K. fluid)	metre^3 (m^3)	2.841 307 E−05
ounce (U.S. fluid)	metre^3 (m^3)	2.957 353 E−05
peck (U.S.)	metre^3 (m^3)	8.809 768 E−03
pint (U.S. dry)	metre^3 (m^3)	5.506 105 E−04
pint (U.S. liquid)	metre^3 (m^3)	4.731 765 E−04
quart (U.S. dry)	metre^3 (m^3)	1.101 221 E−03
quart (U.S. liquid)	metre^3 (m^3)	9.463 529 E−04
stere	metre^3 (m^3)	1.000 000*E+00
tablespoon	metre^3 (m^3)	1.478 676 E−05
teaspoon	metre^3 (m^3)	4.928 922 E−06
ton (register)	metre^3 (m^3)	2.831 685 E+00
yard^3	metre^3 (m^3)	7.645 549 E−01

VOLUME/TIME (INCLUDES FLOW)

foot^3/minute	metre^3/second (m^3/s)	4.719 474 E−04
foot^3/second	metre^3/second (m^3/s)	2.831 685 E−02
inch^3/minute	metre^3/second (m^3/s)	2.731 177 E−07
yard^3/minute	metre^3/second (m^3/s)	1.274 258 E−02
gallon (U.S. liquid)/day	metre^3/second (m^3/s)	4.381 264 E−08
gallon (U.S. liquid)/minute	metre^3/second (m^3/s)	6.309 020 E−05

WORK (SEE ENERGY)

REFERENCES

American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103:

(1) Definitions A 340, Terms, Symbols, and Conversion Factors Relating to Magnetic Testing
(2) Method D 2161, Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity
(3) Petroleum Measurement Tables D 1250
(4) Rec. Practice D 1914, Conversion Units and Factors Relating to Atmospheric Analysis
(5) Rec. Practice E 29, for Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values

American National Standards Institute, Inc., 1430 Broadway, New York, N. Y. 10018:

(6) American National Standard Y10.19-1968, Letter Symbols for Units Used in Science and Technology

International Organization for Standardization, Geneva, Switzerland (available from American National Standards Institute):

(7) ISO/R370-1964, Conversion of Toleranced Dimensions from Inches into Millimetres and Vice Versa
(8) ISO/R31/Part I—1965, Basic Quantities and Units of the SI
(9) ISO/R31/Part II—1958, Quantities and Units of Periodic and Related Phenomena
(10) ISO/R31/Part III—1960, Quantities and Units of Mechanics
(11) ISO/R31/Part IV—1960, Quantities and Units of Heat
(12) ISO/R31/Part V—1965, Quantities and Units of Electricity and Magnetism
(13) ISO/1000-1973, SI Units and Recommendations for the Use of Their Multiples and of Certain Other Units

National Bureau of Standards (documents available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402):

(14) "Unit of Weights and Measures (United States Customary and Metric): Definitions and Tables of Equivalents," *NBS Misc. Publ. MP286*, May 1967

(15) Judson, L. V., "Weights and Measures Standards of the the United States, a Brief History," *NBS Misc. Publ. 247*, October 1963
(16) "Units and Systems of Weights and Measures. Their Origin, Development, and Present Status," *NBS Letter Circ. LC 1035*, January 1960
(17) "Policy for NBS Usage of SI Units," *NBS Tech. News Bull.*, Vol 57, No. 6, June 1973
(18) Chart—"The Modernized Metric System," *NBS Spec. Publ. 304*, 1972
(19) Page, C. H. and Vigoureux, P., "The International System of Units (SI)," *NBS Special Publication 330*, 1972.

Miscellaneous:

(20) Mechtly, E. A., "The International System of Units—Physical Constants and Conversion Factors," National Aeronautics and Space Administration, Publication SP-7012. Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
(21) Palmer, J. F., "The International System of Units Handbook," Brown Engineering Co., Inc., Huntsville, Ala.
(22) McNish, A. G., "The International System of Units," *Materials Research and Standards*, Am. Soc. Testing Mats., Vol 5, No. 10, October 1965
(23) "Changing to the Metric System, Conversion Factors, Symbols, Definitions," Nat. Physical Lab., Her Majesty's Stationery Office, London, England, 1972
(24) *Metric Standards for Engineering*, British Standard Handbook No. 18 (1972)
(25) Chart—"Quantities and SI Units," Nederlands Normalisatie Instituut, Polakweg 5, Rijswijk (ZH), Netherlands

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