ASTM METRIC PRACTICE GUIDE

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

HANDBOOK 102

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ASTM METRIC PRACTICE GUIDE

Prepared by
Ad Hoc Committee on Metric Practice
American Society for Testing and Materials

National Bureau of Standards Handbook 102

Issued March 10, 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 — Price 40 cents

Foreword

The increased use of the International System of Units (SI), a modernized version of the Metric System, both in the United States and abroad has created many problems of conversion for engineers, manufacturers, and people engaged in international trade. To facilitate conversion between the United States Customary Units and the SI units, the American Society for Testing and Materials (ASTM) established an Ad Hoc Committee on Metric Practice charged with the preparation of a Metric Practice Guide to provide the technical committees of ASTM with conversion procedures and factors to implement the Society's policy. Because of its usefulness to many segments of the American public, the National Bureau of Standards (NBS) with concurrence of the ASTM, has undertaken to make the Second Edition of the Metric Practice Guide available for public distribution.

This second edition, much larger and more complete than the first, represents consensus recommendations of the Ad Hoc Committee with which NBS has been happy to cooperate. Although in some minor ways ASTM practice does not conform to NBS practice, the document is being reproduced exactly as prepared for circulation within ASTM.

I wish to commend ASTM for the valuable public service they have performed in developing this document. The Bureau is pleased to have the opportunity to give it the wider dissemination which it so rightly deserves.

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Library of Congress Catalog Card Number: 67—60034

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SECOND EDITION

DECEMBER, 1966

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia, Pa. 19103

Preface

This second edition supersedes the first edition dated January 1964. The text has been rewritten to conform to practices adopted by other organizations. Conversion factors used have been approved by the National Bureau of Standards and are published in National Aeronautics and Space Administration (NASA) publication SP-7012, "The International System of Units," 3rd edition.

Continuing surveillance will be needed and periodic revisions made as further experience in the use of the Guide may dictate. Furthermore, consideration will be given to the inclusion of additional units when adopted by the General Conference on Weights and Measures (CGPM). Any suggestions for improvements should be submitted to the Headquarters of the Society.

December, 1966

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ASTM Metric Practice Guide

(A GUIDE TO THE USE OF THE INTERNATIONAL SYSTEM OF UNITS)
ISSUED JANUARY, 1964; REVISED DECEMBER 1966

FOREWORD

To continue to serve the best interests of science and industry the American Society for Testing and Materials is actively cooperating with other standardization organizations in the development of simpler and more universal metrology practices. In some industries both here and abroad, U.S. customary (and British) units are gradually being replaced by those of a modernized metric[1] system known as Système International d'Unités (SI). Recognizing this trend, the Society considers it important to prepare for broader use of the modernized metric system through coexistence of these two major systems. This policy involves no change in standard dimensions, tolerances, or performance specifications. Current "inch-pound" units will therefore be published as before along with their modern metric (SI) equivalents, but conversions in the opposite directions will be avoided.

This Guide is offered primarily to provide the technical committees of ASTM with conversion procedures and factors to implement this Society policy.

1. Scope

1.1 This Metric Practice Guide deals with the conversion, from one system of units to another, of quantities that are in general use in ASTM standards and other publications, and includes the units most frequently used in the various fields of science and industry. The conversion factors given are from U.S. customary (and British) units[2] to those of the Système International d'Unités[3] which is officially abbreviated as SI in all languages. SI units are frequently referred to as metric units and this practice is continued in the

[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."

[2] This and other terms are defined in Appendix A1.

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

present Guide. Also included in the Guide are factors for converting U.S. customary units to units based on the cgs system that have been used in engineering practice such as kilograms-force per square millimeter (kgf/mm^2) for stress or pressure in addition to the SI unit—newtons per square meter (N/m^2). The present Guide has been prepared for use in the application of these factors and to facilitate the use of such metric equivalents in ASTM standards and other publications.

1.2 The recommendations contained herein[4] 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 the International System of Units (the modernized metric system) is generally superior to other systems; and that the metric 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 metric units.

1.2.2 That various U.S. customary units, particularly the inch and the pound, are the fundamental units used in the standards followed by a large part of the world's manufacturing industry; and that this will continue to be true for some time.

1.2.3 That unit usage can and should be simplified in the fields of interest to ASTM; that one means toward such simplification is the elimination of obsolete and unneeded units; and that another is a better understanding of the rational links between metric units and units of other systems.

1.3 This Metric Practice Guide will, insofar as practicable, be followed in all ASTM publications. The principles set forth in this Guide are best applied by the committee responsible for a standard or by the author of a specific document. The editorial staff of ASTM will suggest changes when inappropriate units are used.

2. SI or Metric Units and Symbols

2.1 The SI or metric system consists of six 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.

2.1.1 *Base Units:*[5]

Quantity	Unit	SI Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	degree Kelvin	°K
luminous intensity	candela	cd

[4] This section is adapted from IEEE Recommended Practice for Units in Published Scientific and Technical Work, IEEE Spectrum, March 1966, pp. 169–173.

[5] The six base and two supplementary SI units are defined in Appendix A2. In chemistry a further base unit has been considered necessary. The use of the mole (symbol-mol) for this purpose corresponding to the base quantity "amount of substance," is recommended by the ISO.

2.1.2 *Supplementary Units:*[5]

plane angle	radian	rad
solid angle	steradian	sr

2.1.3 *Derived Units:*[6]

acceleration	meter per second squared	m/s^2
angular acceleration	radian per second squared	rad/s^2
angular velocity	radian per second	rad/s
area	square meter	m^2
capacitance	farad	F

Quantity	Unit	SI Symbol	Formula
density	kilogram per cubic meter	kg/m^3	...
electric capacitance	farad	F	$A \cdot s/V$
electric charge	coulomb	C	$A \cdot s$
electric field strength	volt per meter	V/m	...
electric resistance	ohm	Ω	V/A
electromotive force	volt	V	W/A
energy	joule	J	$N \cdot m$
force	newton	N	$kg \cdot m/s^2$
frequency	hertz	Hz	s^{-1}
illumination	lux	lx	lm/m^2
inductance	henry	H	$V \cdot s/A$
kinematic viscosity	square meter per second	m^2/s	...
luminance	candela per square meter	cd/m^2	...
luminous flux	lumen	lm	$cd \cdot sr$
magnetic field strength	ampere per meter	A/m	...
magnetic flux	weber	Wb	$V \cdot s$
magnetic flux density	tesla	T	Wb/m^2
magnetomotive force	ampere	A	...
potential difference	volt	V	W/A
power	watt	W	J/s
pressure	newton per square meter	N/m^2	...
quantity of heat	joule	J	$N \cdot m$
stress	newton per square meter	N/m^2	...
velocity	meter per second	m/s	...
viscosity	newton-second per square meter	$N \cdot s/m^2$	
voltage	volt	V	W/A
volume[7]	cubic meter	m^3	...
work	joule	J	$N \cdot m$

2.1.4 *Multiple and Submultiple Units* (*see 4.4*):

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

[6] These units will be used in the International System of Units (SI) without prejudice to other units that may be added in the future.

[7] The General Conference on Weights and Measures (CGPM) in 1964 redefined the liter to be exactly 1000 cm^3. Hence, the term liter is no longer an acceptable metric unit and should be replaced by the cubic decimeter, expressed as 10^{-3} m^3, dm^3, or 1000 cm^3.

Multiplication Factors	Prefix	SI Symbol
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

3. Rules for Introducing Metric Units

3.1 Metric units of measurement shall be included in all new drafts and revisions of ASTM standards and other publications.

3.2 Each technical committee shall have the option of using either U.S. customary or metric units as the base for standards under its jurisdiction.

3.2.1 When a standard is based on U.S. customary units, these should appear first with their SI equivalent in parentheses or in a supplementary table as permitted by 3.6.3.[8]

3.2.2 When a standard is based on metric units U.S. customary units are usually omitted. If it is desirable to include the latter, the metric unit shall appear first.

3.3 The system of units to be used in referee decisions shall, in doubtful cases, be stated in a note in each standard. The note should read as follows:

Note—The values stated in U.S. customary units are to be regarded as the standard. The metric equivalents of U.S. customary units given in the body of the standard and in the appendix (if any) may be approximate.

3.4 The use of mixed units, particularly those compounded from different systems, should be avoided wherever practicable. For example,

(*a*) use 12.75 lb, not 12 lb 12 oz.

(*b*) use 0.1789 rad or 10.25 deg, not 10 deg 15 min.

(*c*) use kilograms per cubic meter (kg/m^3), not kilograms per gallon (kg/gal).

3.5 Certain units such as kilograms-force have been widely used in engineering practice, even in countries that have officially adopted the modernized metric system. Consequently certain deviations from this system as described in 4. Rules for Metric Style and Usage, may be used during the transition period from the inch-pound system to SI.

3.6 Where metric equivalents are used side by side with U.S. customary units in text or on drawings, the metric equivalent should be enclosed in parentheses and identified with the appropriate metric unit symbol; similar rules apply when these units are given as equivalents on metric drawings (see Fig. 1).

3.6.1 For more complicated drawings, the dimensions should be indicated by letters and the corresponding inch and metric dimensions shown in an accompanying table (see Fig. 2).

3.6.2 In the case of charts or graphs, dual scales may be used to advantage (see Fig. 3).

3.6.3 Tabular data may be presented as shown in Table 1 or Table 2. When values are grouped in one table as in Table 2, they should be listed in order of magnitude with the corresponding conversion values given in an adjacent column (see 3.2.1 and 6.6).

[8] In areas where the practice prevails of placing the metric equivalents first, this practice may be continued.

3.7 All drawings and tables should be suitably labeled to identify the fundamental units of measurement used.

3.8 Nominal sizes or identification of standard parts should preferably remain in the units of the system from which the nominal was taken. For example, a ¼-20 UNC 2A screw thread should continue to be identified in

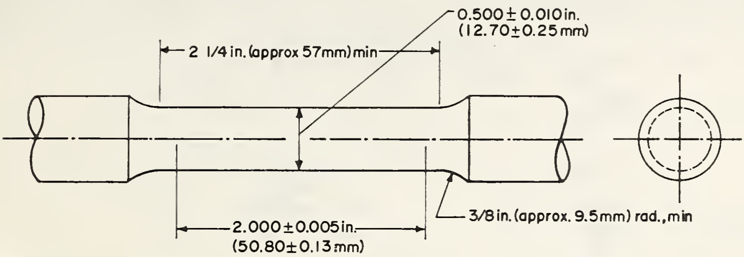
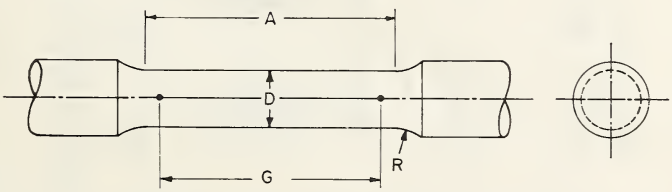


FIG. 1—Standard 0.500-in. (12.7-mm) Round Tension Test Specimen with 2-in. (50.8-mm) Gage Length.



DIMENSIONS OF TEST SPECIMENS

	Standard Specimen		Small-Size Specimen Proportional to Standard	
	in.	mm	in.	mm
Nominal Diameter	0.500	12.5	0.350	8.75
G—Gage length.......	2.000 ± 0.005	50.80 ± 0.13	1.400 ± 0.005	35.56 ± 0.13
D—Diameter.........	0.500 ± 0.010	12.70 ± 0.25	0.350 ± 0.007	8.89 ± 0.18
R—Radius of fillet, min	⅜	approx 9.5	¼	approx 6.5
A—Length of reduced section, min........	2¼	approx 57	1¾	approx 44.5

FIG. 2—Standard 0.500-in. (12.7-mm) Round Tension Test Specimen with 2-in. (50.8-mm) Gage Length and Example of Small-Size Specimens Proportional to the Standard Specimen.

this manner, regardless of whether it is a part of a metric tabulation or shown on a metric drawing or illustration. However, on metric drawings, tabulations and illustrations, the controlling dimensions of the part, such as the pitch and major or minor diameters in the case of a thread, should be in millimeters on millimeter drawings or tables; similar rules apply for millimeter nominals and controlling dimensions when used on inch drawings or tables. Wire diameter and thickness of sheet and strip should preferably be designated by their nominal dimensions. When designated by gage, the gage number and the appropriate gage system should be specified; for example, American (Awg), Birmingham (Bwg), Brown and Sharpe (B&S).

4. Rules for Metric Style and Usage

4.1 *General*—The established metric units—base, supplementary, derived, and combinations thereof (see 2. SI or Metric Units and Symbols) with

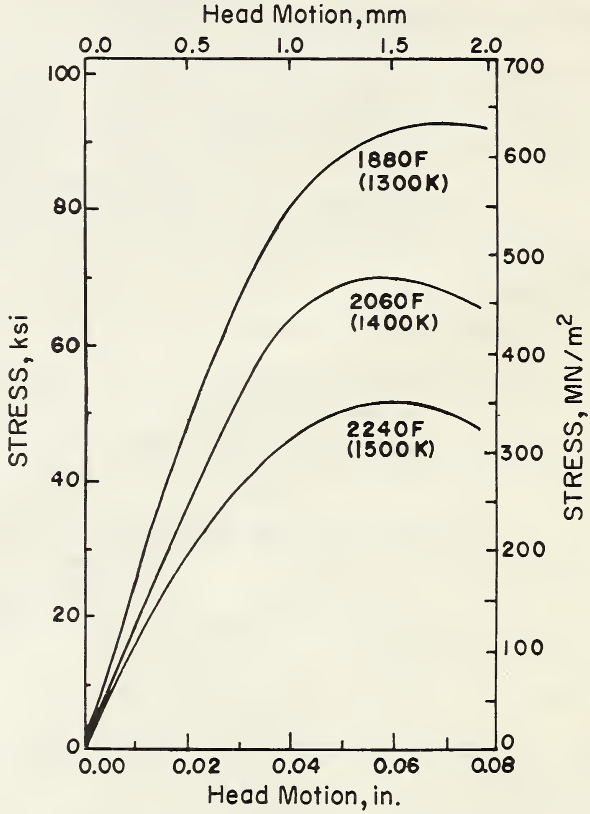


Fig. 3—Stress-Extension Curves for Cr-Ti-Coated Vanadium Alloy at Elevated Temperatures.

appropriate multiple or submultiple prefixes—should be used. Questions concerning appropriate combination units may be resolved by referring to the table of conversion factors (Appendix A3) for the appropriate quantity or the following rules for establishing appropriate combinations. A few exceptions to strict adherence to metric units are given in 4.3.

4.2 *Preferred Usage:*

4.2.1 *Mass, Force, and Weight:*

4.2.1.1 The principal departure of SI from the more familiar form of the cgs and MKSA systems is use of the newton as a practical unit of force instead of the kilogram-force. Likewise, combination units including force, for example, pressure (N/m²), work (N·m = J), power (N·m/s = W), use the newton instead of kilograms-force.

4.2.1.2 The term "mass" (unit = kilogram) is used to specify the quantity of matter contained in material objects and is independent of their location in the universe. The term weight (unit = newton) is used as a measure of gravitational force acting on a material object at a specified location and generally varies as the object changes location. Although a constant mass has an approximately constant weight on the surface of the earth, the pound-force and the kilogram-force are not the forces exerted by the earth's gravitation on a pound-mass or a kilogram-mass to high accuracy in locations that depart significantly from mean sea level. The gravitational force varies by about 0.5 per cent over the Earth's surface. Therefore, the variation of gravity must be taken into account when greater accuracy is required. For convenience, the precise expression of forces on a gravitational basis is related to the International standard gravity value ("standard acceleration") 9.80665 m/s². For example: a man of 70.0 kg mass working at the National Bureau of Standards in Washington, D.C., which is near sea level, would weigh, at standard gravity, 70.0 kg × 9.806 65 m/s² or 686.5 N whereas the

TABLE 1—METHOD OF PRESENTATION OF EQUIVALENTS IN TABLE WHEN SPACE PERMITS.

TENSION TEST DATA FOR UNCOATED VANADIUM ALLOY SHEET MATERIAL

Alloy	Spec. No.	Temperature		Tensile Strength		Per Cent Elongation in 1 in. (25 mm)[a]
		deg F	deg K[a]	ksi	MN/m²	
A..............	1	80	300	147.3	1016	33
A..............	2	80	300	145.5	1004	32
A..............	3	1880	1300	71.5	493	12
A..............	4	2240	1500	18.4	127	17
B..............	1	80	300	101.5	700	28
B..............	2	80	300	101.5	700	29
B..............	3	1880	1300	44.7	308	19
B..............	4	2240	1500	14.8	102	21

[a] Approximate.

TABLE 2—ALTERNATIVE PRESENTATION OF EQUIVALENTS IN A SUPPLEMENTARY TABLE.

POUNDS-FORCE PER SQUARE INCH TO MEGANEWTONS PER SQUARE METER

psi	MN/m²
1 000	6.9
57 000	393
74 000	510
85 000	586
102 000	703
120 000	827
125 000	862

same man working at an elevation such as that of Denver, Colorado, would weigh only 70.0 kg × 9.796 12 m//s² or 685.7 N. On the other hand, the same man standing on the surface of the moon, where the gravitational acceleration is 1.62 m/s², would weigh approximately 113 N.

4.2.1.3 The term mass or unit mass should be used to indicate the quantity of matter in an object and the previous practice of using weight in such cases should be avoided. The term weight should be used only when specification of the gravitational forces requires it, and then it should be accompanied by a statement specifying the location and gravitational acceleration at that point.

4.2.1.4 To facilitate transition to metric units, a distinction should be made between (*1*) force or load and (*2*) mass, both of which have traditionally been termed weight. For force or load, gf, kgf, or lbf should be used; for mass, g, kg, lbm (preferred), or lb.

4.2.1.5 Certain physical quantities involving force and mass units may cause confusion due to the use of the same name for the units of both quantites. The newton was introduced as a unit of force to avoid this confusion and such problems are avoided if force and mass units are identified and converted accordingly. For example, the combination unit foot-pound-force per pound-mass used to measure efficiency could be considered (erroneously) to have the dimension of feet and might be converted to meters; however, considering the definition of the units, it should be converted to newton-meters per kilogram (N·m/kg) or joules per kilogram (J/kg) in metric units. In many cases, the relationship between newtons, seconds, and kilograms given by the first law of motion (f = ma) should be used to simplify units (that is, the newton is equal to a kilogram-meter per second per second, N = kg·m/s²).

4.2.2 *Combination Units*—To maintain the coherence of the system, only metric units themselves and not their multiples or submultiples should be used in combination to form derived units. Thus, the metric unit of pressure is newtons per square meter (N/m²) and not newtons per square centimeter (N/cm²), or newtons per square millimeter (N/mm²). Prefixes may, however, be applied to the numerator of the resulting combination; thus, meganewton per square meter (MN/m²) or mega(newton per square meter), for greater clarity. Exceptions are given in 4.3.4 and 4.4.3. The general rule is that prefixes should not be used in the denominator. Also to maintain the coherence of the system, only units themselves (without prefixes) should be used for insertion in equations. (See also 4.5.5.)

4.3 *Exceptional Practices*—Certain pseudo-metric technical units, such as cgs and MKSA units that are not a part of SI, have wide acceptance in countries that have officially adopted SI. Some deviations from the strict application of the above rule, therefore, will prevail for an interim period, but such deviations should not appear in calculations with other quantities.

4.3.1 *Temperature*—The preferred temperature scale in the metric system is the Thermodynamic Kelvin Temperature Scale but the International Practical Kelvin Temperature Scale of 1960 is used in most measurements. The International Practical Celsius Temperature Scale (formerly called the centigrade scale) may be used when it is advantageous. Note that units of the

Kelvin and Celsius temperature interval are identical and that a Kelvin temperature may be derived by adding 273.15 to the Celsius temperature. The latter (273.15 K) corresponds to the freezing point of water which is 0 Celsius or 0 centrigrade, whereas the triple point is 273.16 K, or 0.01 C.

4.3.2 *Time*—The preferred metric unit for time rates or total time is the second. However, because of practical advantages in the use of hours, minutes, and days for certain purposes, these units are permissible at the discretion of the committee concerned (see 4.3).

4.3.3 *Angles*—The radian is the preferred metric unit; however, the arc degree, arc minute, and arc second may be used for the measurement of plane angles. Decimal multiples of the radian or degree are preferred, however. Solid angles should be measured in steradians.

4.3.4 *Stress and Pressure*—The preferred metric unit of pressure and stress is the newton per square meter (see 4.2.2). However, in some countries using cgs and MKSA units, these measurements are given in kilograms-force per square centimeter or kilograms-force per square millimeter. Where the inclusion of such units in an ASTM standard is desirable in the interest of international cooperation, the kilogram-force per square millimeter (or per square centimeter) may be used provided the metric unit (newtons per square meter) is also given in parentheses (see 4.3, 5.7 and 6. General Instructions). Meanwhile, where the kilogram is retained as a unit of force, it shall be so designated (kgf) to distinguish it clearly from the metric units of mass (kg).

4.3.5 *Miscellaneous Nonmetric Units*—When a nonmetric unit is, at present, too widely used to be eliminated immediately, its use may be continued with the metric equivalent in parentheses. Such terms include the horsepower to measure mechanical power and the torr to measure air pressure. These exceptions are not intended to be permanent protection for irrational practices, however, and such anachronisms should be eliminated as rapidly as possible.

4.4 *Application of Prefixes:*

4.4.1 *General*—Approved 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 microamps or 12.3×10^{-9} A becomes 12.3 nA.

4.4.2 *Selection*—Double prefixes and hyphenated prefixes should not be used when single prefixes are available. For example,

> use GW (gigawatt), not kMW and
> use pF (picofarad), not $\mu\mu$F.

4.4.3 *Combinations*—A prefix placed before a symbol for a unit is considered a new symbol, thus mm = (mm) and $mm^2 = (mm)^2 = \mu(m^2)$. Prefixes should not be used in the denominator of compound units, except for kilogram (kg). Since the kilogram is a base unit of SI, this particular multiple unit is not a violation, for example, use 200 J/kg, not 2 dJ/g.

4.5 *Preferred Style:*

4.5.1 *Capitalization*—In general, abbreviations of metric units are not capitalized unless the unit is derived from a proper name; thus, Hz for H. R. Hertz, but m for meter. Unabbreviated metric terms are not capitalized except for temperature designations. For example, hertz, newton, Kelvin, and Celsius. Numerical prefixes and their symbols are not capitalized, except for the symbols T, G, and M (mega) (see 2.1.4).

4.5.2 *Plurals*—Unabbreviated metric units form their plurals in the usual manner. Metric abbreviations are always written in singular form. For example,

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

4.5.3 *Punctuation*—Periods should not be used after metric abbreviations except at the end of a sentence. In the case of other abbreviations, a period should be used when the abbreviation forms a word; for example, "in." is the abbreviation for inch(es) and "Fig." for Figure(s). (See ASTM Style Manual.)

4.5.4 *Number Grouping*—To facilitate the reading of numbers having four 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

4.5.5 *Equations*—When U.S. customary units appear in equations, the metric equivalents should be omitted. Instead of inserting the metric equivalents in parentheses as in the case of text or small tables as specified in 3.2, the equations should be restated using metric 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 metric units.

5. Rules for Conversion and Rounding

5.1 *General:*

5.1.1 Unit conversions should be handled with careful regard to the implied correspondence between the accuracy of the data and the given number of digits.

5.1.2 In all conversions, the number of significant digits retained should be such that accuracy is neither sacrificed nor exaggerated.

5.1.3 The most accurate equivalents are obtained by multiplying the specified quantity by the conversion factor exactly as given in Appendix A3 and then rounding in accordance with 5.3 to the appropriate number of significant digits (see 5.4). For example, to convert 11.4 ft into meters: 11.4×0.3048 m = 3.474 72 m, which rounds to 3.47 m (see 5.4.6).

5.1.4 There is less assurance of accuracy when the equivalent is obtained by first rounding the conversion factor to the same number of significant digits as in the specified quantity, performing the multiplication, and then rounding the product in accordance with 5.4. This procedure may provide approximate values but it is not recommended for tolerances or limiting values. For example, again converting 11.4 ft into meters: 11.4 × 0.305 m = 3.4770 m which rounds to 3.48 m (see 5.4.6). This compares with the value of 3.47 m obtained by the more exact method of 5.1.3.

5.1.5 Where feasible, the rounding of metric equivalents should be in rational, convenient, whole numbers. The word approximately (approx) should be employed to identify such loose equivalents. For example, if only an approximate converted value is desired the converted value computed in the example in 5.1.4 might be expressed as "approx 3.5 m" or even "approx 3 m."

TABLE 3—ROUNDING OF MINIMUM AND MAXIMUM LIMITS.

NOTE—The table can be extended on the same basis in either direction as the need arises. Use of the table will result in maximum differences of 1 per cent between the actual and rounded values.

Numerical Range		Round to Nearest
from	but less than	
0.005	0.025	0.0001
0.025	0.05	0.0005
0.05	0.25	0.001
0.25	0.5	0.005
0.5	2.5	0.01
2.5	5	0.05
5	25	0.1
25	50	0.5
50	250	1
250	500	5
500	2 500	10
2 500	5 000	50
5 000	25 000	100
25 000	50 000	500
50 000	250 000	1 000

5.1.6 Where dimensional interchangeability is involved, the methods described in 5.5.2 should be employed. Selection of Method A or Method B will depend upon the functional interchangeability required and on the relationship of the limits in the original dimensioning system to the limits of mating or related parts.

5.1.7 Appendix A3 contains conversion factors that give exact (as defined in terms of the base units) or five-figure (or better) accuracy for implementing these rules.

5.2 *Rounding Minimum and Maximum Limits:*

5.2.1 Unless greater accuracy is justifiable, the equivalents should be rounded in accordance with the applicable values in Table 3.

5.3 *Rounding Figures:*[9]

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

[9] Adapted from "USA Standard Practice for Inch-Millimeter Conversion for Industrial Use," USASI B48.1.

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

5.3.1.2 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 cut off to four digits, would be 8.377; if cut off to three digits, 8.38.

5.3.1.3 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 cut off to three digits, becomes 4.36. 4.355 would also round to the same value, 4.36, if cut off to three digits.

5.4 *Significant Digits:*[10]

5.4.1 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.

5.4.2 Any digit that is necessary to define the specific value or quantity is said to be significant. When measured to the nearest meter, 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 words, 157.4 was rounded to 157; in the second case, the measurement in hundredths, 157.36 was rounded to 157.4.

5.4.3 Zeros may be used either to indicate a specific value, like any other digit, or to indicate the magnitude of a number. The 1960 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

5.4.4 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.

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[10] See also ASTM Recommended Practices E 29, for Designating Significant Places in Specified Limiting Values, *1966 Book of ASTM Standards*, Part 30.

5.4.5 The rule for addition and subtraction is that the answer shall contain no more significant digits to the right than is contained 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
217 985 000
96 432 768
477 417 768

The total indicates a precision that is not valid. The numbers should first be rounded to *one more right-hand significant digit* than is contained in the least accurate number, illustrated as follows:

163 000 000
218 000 000
96 400 000
477 400 000

The answer should then be rounded to 477 000 000. The result of rounding the second number, 217 985 000 should be noted; since the digit to the right of 217.9 was greater than 5, the 9 had to be raised to 10, thereby resulting in the number 218 000 000.

5.4.6 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 to the least accurate number. The following illustration highlights this difference:

Multiplication:	$113.2 \times 1.43 = 161.876$, rounded to 162
Division:	$113.2 \div 1.43 = 79.16$, 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.

5.4.7 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.

5.5 *Conversion of Dimensions and Tolerances:*[11]

5.5.1 *Dimensions Without Tolerances:*

5.5.1.1 If no tolerance is given and the dimension is not approximate, give the converted dimension in millimeters to one additional significant digit when the first digit in the metric value is smaller than the first digit in the U.S. customary value. For example, 5.4 in. = 137.16 mm, which rounds to 137 mm. When the first digit in the metric value is larger than the first digit in the U.S. customary value, round the converted dimension to the same number of significant digits as given in the U.S. customary value. For example, 2.3 in. = 58.42 mm, which rounds to 58 mm. In tool, gage, and similar work it is usually advisable to limit the millimeter equivalent to not more than three decimal places, as this represents as high a precision as is ordinarily required.

5.5.1.2 If no tolerance is given and the dimension is approximate, calculate the converted dimension in millimeters to one additional significant digit and round appropriately. If the rounded converted dimension is given to fewer significant digits than the original dimension, insert the word "approximately" before the converted dimension. For example, 77 in. = 1.9558 m, which rounds to approx 2 m.

5.5.1.3 If the dimensions are given in common fractions of an inch, give the converted dimensions in millimeters to the implied or required precision of the value to be converted.

5.5.1.4 As an alternative to 5.1.3 and 5.1.4, conversion tables and charts are frequently provided for the rapid determination of converted values of commonly used quantities by addition only. Table 4 is of this type, and provides values for converting inches to millimeters. 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 4 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 millimeters,

$$\begin{array}{rcl} 2.0000 \text{ in.} & = & 50.800\ 00 \text{ mm exactly} \\ 0.4600 \text{ in.} & = & 11.684\ 00 \text{ mm exactly} \\ \underline{0.0037 \text{ in.}} & = & \underline{0.093\ 98 \text{ mm exactly}} \\ 2.4637 \text{ in.} & = & 62.577\ 98 \text{ mm exactly} \end{array}$$

or, correct to three decimal places:

$$2.4637 \text{ in.} = 62.578 \text{ mm}$$

In this example, to maintain accuracy during conversion without retaining an unnecessary number of digits, the rounded millimeter equivalent of each group is carried to one decimal place more than the inch value being con-

[11] Parts of this section are adapted from the SAE Recommended Practice J916 (1966 SAE Handbook).

verted. The sum of the group of equivalents is then rounded to one less decimal place than the original inch value.

5.5.1.5 Table 5 provides values for the conversion of decimal and fractional values of an inch to millimeters. Combinations of inch and fractional inch-millimeter equivalents may be tabulated to obtain the desired millimeter conversion. As in the example in 5.5.1.4, the millimeter value should be rounded to one less than the decimal equivalent of the inch fraction taken to the intended or implied accuracy.

5.5.2 *Toleranced Dimensions*—The use of the conversion factor of 1 in. = 25.4 mm (exactly) 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

TABLE 4—INCH-MILLIMETER EQUIVALENTS.

Note—All values in this table are exact, based on the conversion factor 1 in. = 25.4 mm (exactly). By manipulation of the decimal point any decimal value or multiple of an inch may be converted to its exact equivalent in millimeters. A table of equivalents covering the range from 0.001 to 1.000 in. may be obtained from the Headquarters of the Society.

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	...	...	...	...	...	...	...	...	...

the degree of accuracy in the converted values compatible with that of the original values. If maximum and minimum values are specified, the total tolerance is the difference between the two values.

5.5.2.1 *General*—The number of decimal places given in Table 6 for rounding toleranced dimensions relates the degree of accuracy to the size of the tolerance 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.

5.5.2.2 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, considered as being acceptable for interchangeability, serve as a basis for inspection.

5.5.2.3 In Method B, rounding is done systematically *toward the interior*

TABLE 5—INCH-MILLIMETER EQUIVALENTS OF DECIMAL AND COMMON FRACTIONS.
From $\frac{1}{64}$ to 1 in.

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

TABLE 5—*Continued.*

Inch	½'s	¼'s	8ths	16ths	32nds	64ths	Millimeters	Decimals of an Inch[a]
						49	19.447	0.765 625
					25	50	19.844	0.781 25
						51	20.241	0.796 875
				13	26	52	20.638	0.812 5
						53	21.034	0.828 125
					27	54	21.431	0.843 75
						55	21.828	0.859 375
			7	14	28	56	22.225[a]	0.875 0
						57	22.622	0.890 625
					29	58	23.019	0.906 25
						59	23.416	0.921.875
				15	30	60	23.812	0.937 5
						61	24.209	0.953 125
					31	62	24.606	0.968 75
						63	25.003	0.984 375
1	2	4	8	16	32	64	25.400[a]	1.000 0

[a] Exact.

TABLE 6—ROUNDING TOLERANCES.
(Inches to Millimeters)

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

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 insures that even in the most unfavorable cases neither of the two original limits will be exceeded (nor diminished) by more than 2 per cent 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 millimeters by means of the conversion factor 1 in. = 25.4 mm (see Table 4).

(*c*) Round the results obtained to the nearest rounded value as indicated in Table 6, 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 as in the case of mating parts. In extreme cases, this method may increase the lower limit a maximum of 4 per cent of the tolerance and decrease the upper limit a maximum of 4 per cent 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:[12] 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 millimeters 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 6). Rounding these values to the nearest 0.01 mm, the values in millimeters to be employed for these two limits are	49.12 to 49.94
Method B—Rounding towards the interior of the tolerance, millimeter values for these two limits are	49.13 to 49.93

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

5.5.2.4 *Special Methods for Basic Size and Deviations*—In order to avoid accumulation of rounding errors, the two limits of size must be converted separately; 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.

5.5.2.5 *Special Methods for Limitation Imposed by Accuracy of Measurements*—If the increment of rounding given for the tolerances in Table 6 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 per cent of the tolerance.

5.5.2.6 *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, these roundings depending on twice the original radial tolerance, that is, the diameter of the tolerance zone.

5.5.2.7 *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 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 5.3. For

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

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 millimeters, must be corrected by 0.022 × 0.05 = 0.0011 mm, in the appropriate sense, before being rounded.

5.5.2.8 *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.

5.6 *Conversion of Temperature:*

TABLE 7—CONVERSION OF TEMPERATURE TOLERANCE REQUIREMENTS.

Tolerance, deg F	±1	±2	±5	±10	±15	±20	±25
Tolerance, deg K or deg C	±0.5	±1.1	±3	±5.5	±8	±11	±14

5.6.1 The temperature in degrees Kelvin (t_K) equals (5/9) (t_F + 459.67) where t_F is the temperature in degrees Fahrenheit.

5.6.2 The temperature in degrees Celsius (t_C) equals (5/9) (t_F − 32), where t_F is the temperature in degrees Fahrenheit.

5.6.3 To convert a temperature range in Fahrenheit degrees to a temperature range in Celsius or Kelvin degrees, multiply the range in Fahrenheit degrees by 5/9 or divide the range in Fahrenheit degrees by 1.8.

5.6.4 All equivalents should be to the nearest tenth of a Kelvin or Celsius degree, with the following exceptions:

5.6.4.1 Fahrenheit temperatures indicated to be "approximate," "not higher than," "not lower than," or designated as a maximum or a minimum shall have their equivalents shown to the nearest whole Kelvin or Celsius degree and rounded to the appropriate number of significant digits, for example,

$$100 \pm 5\ \mathrm{F} = 38 \pm 3\ \mathrm{C}$$
$$1000 \pm 50\ \mathrm{F} = 540 \pm 30\ \mathrm{C}$$

5.6.4.2 Tolerance conversions should be as shown in Table 7.

5.7 *Conversion of Pressure and Stress:*

5.7.1 The correct metric unit for expressing pressure and stress is newtons per square meter (N/m^2). However, for the present, to facilitate communication with those international groups (ISO) which have been using cgs units, the unit kilograms-force per square millimeter (kgf/mm^2) may be used (see 4.3.4).

5.7.2 Either conversion (to N/m^2 or to kgf/mm^2) may be made by proper use of the factors given in Appendix A3. These factors are: 1 psi = $6.894\ 757 \times 10^3\ N/m^2$, and 1 psi = $7.030\ 70 \times 10^{-4}\ kgf/mm^2$.

5.7.3 Conversions from psi or ksi to meganewtons per square meter or to kilograms-force per square millimeter may be obtained without using such conversion factors by the use of Tables 8 and 9. Values of pressure or stress read from Tables 8 and 9 should be rounded in accordance with 5.3.

6. General Instructions

6.1 The following instructions have been developed to assist the technical committees in the application of the principles expressed in this Guide. More specific application to the problems of each individual committee should be developed by the committee itself in conformance with the pertinent sections of the Guide.

6.2. No attempt should be made to convert values expressed in U.S. customary units to a rounded metric equivalent that might be used or eventually adopted by other countries, but rather the calculated equivalent should be given.

6.3 A specific equivalent, for example, 1.0 in. (25.4 mm), need be inserted only the first time it occurs in each section of a standard.

6.4 In general, multiple and submultiple metric units should be used in steps of 1000. For example, show loads, forces, or weights in mgf, gf, and kgf; lengths in mm, m, and km. The use of centimeters should be avoided, particularly for dimensions under 12 in. (approx 300 mm) unless trade practice makes it desirable.

6.5 In standards that have alternative or optional procedures based on the use of instruments calibrated in either U.S. customary units or in metric units, equivalents need not be included.

6.6 In tables it is preferable to include the metric equivalents next to each individual value, either in parentheses or in an adjoining column (see 3.2 and 3.6.3). If this is impracticable, then the most appropriate alternative given in 6.6.1 or 6.6.2 should be used.

6.6.1 When the size of a table and limitations of space make it impracticable to expand the table to include metric equivalents, the table should be duplicated in metric units. In the case of such duplication, the tables should appear on the same page or on facing pages in the printed standard.

6.6.2 When the number of tables requiring duplication in metric equivalents as described in 6.6.1 would increase the size of a standard by more than three pages, either of the two alternatives described in 6.6.2.1 or in 6.6.2.2 may be used.

6.6.2.1 In cases where the same values appear in numerous places in the tables, a composite table of pertinent metric equivalents similar to Tables 10 and 11 may be appended to the standard.

6.6.2.2 In cases where the composite table described in 6.6.2.1 would increase the size of a standard by more than one page, only the appropriate conversion factors should be included as footnotes to the table to which

TABLE 8—PRESSURE AND STRESS EQUIVALENTS—THOUSAND POUNDS-FORCE PER SQUARE INCH TO MEGANEWTONS PER SQUARE METER.

NOTE 1—This table may be used for obtaining metric equivalents of quantities expressed in psi by multiplying the given values by 10^{-3}, that is, by moving the decimal point three places to the left.

NOTE 2—This table may be extended to values below 1 or above 100 ksi by manipulation of the decimal point and addition as illustrated in 5.5.1.4.

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

ksi	0	1	2	3	4	5	6	7	8	9
	MN/m²									
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	330.9483	337.8431
50....	344.7379	351.6326	358.5274	365.4221	372.3169	379.2116	386.1064	393.0012	399.8959	406.7907
60....	413.6854	420.5802	427.4749	434.3697	441.2645	448.1592	455.0540	461.9487	468.8435	475.7382
70....	482.6330	489.5278	496.4225	503.3173	510.2120	517.1068	524.0015	530.8963	537.7911	544.6858
80....	551.5806	558.4753	565.3701	572.2648	579.1596	586.0544	592.9491	599.8439	606.7386	613.6334
90....	620.5281	627.4229	634.3177	641.2124	648.1072	655.0019	661.8967	668.7914	675.6862	682.5810
100....	689.4757	...	...	...	...	...	...	...	...	...

TABLE 9—PRESSURE AND STRESS EQUIVALENTS—THOUSAND POUNDS-FORCE PER SQUARE INCH TO KILOGRAMS-FORCE PER SQUARE MILLIMETER.

NOTE 1—This table may be used for obtaining metric equivalents of quantities expressed in psi by multiplying the given values by 10^{-3}, that is, by moving the decimal point three places to the left.

NOTE 2—This table may be extended to values below 1 or above 100 ksi by manipulation of the decimal point and addition as illustrated in 5.5.1.4.

NOTE 3—A more extensive table (1 to 199 ksi) may be obtained from the Headquarters of the Society.

Conversion Factors: 1 in. = 25.4 mm (exactly)
1 lbf = 0.453 592 37 kgf (exactly)

ksi	0	1	2	3	4	5	6	7	8	9
	kgf/mm²									
0....	...	0.7031	1.4061	2.1092	2.8123	3.5153	4.2184	4.9215	5.6246	6.3276
10....	7.0307	7.7338	8.4368	9.1399	9.8430	10.5460	11.2491	11.9522	12.6553	13.3583
20....	14.0614	14.7645	15.4675	16.1706	16.8737	17.5767	18.2798	18.9829	19.6859	20.3890
30....	21.0921	21.7952	22.4982	23.2013	23.9044	24.6074	25.3105	26.0136	26.7166	27.4197
40....	28.1228	28.8259	29.5289	30.2320	30.9351	31.6381	32.3412	33.0443	33.7473	34.4504
50....	35.1535	35.8565	36.5596	37.2627	37.9658	38.6688	39.3719	40.0750	40.7780	41.4811
60....	42.1842	42.8872	43.5903	44.2934	44.9965	45.6995	46.4026	47.1057	47.8087	48.5118
70....	49.2149	49.9179	50.6210	51.3241	52.0271	52.7302	53.4333	54.1364	54.8394	55.5425
80....	56.2456	56.9486	57.6517	58.3548	59.0578	59.7609	60.4640	61.1671	61.8701	62.5732
90....	63.2763	63.9793	64.6824	65.3855	66.0885	66.7916	67.4947	68.1977	68.9008	69.6039
100...	70.3070	...	...	...	...	...	...	...	...	...

they are applicable. Complete tables of equivalents similar to Tables 4 and 8 will be included in the back of the pertinent part of the Book of ASTM Standards.

6.7 When a standard specifies that results should be expressed in a U.S. customary unit in a general sense, the preferred metric unit should be inserted. For example, "Report the twist of yarns in twists per inch (or twists per meter)" not ". . . in twists per inch (25.4 mm)."

TABLE 10—INCH-MILLIMETER EQUIVALENTS.[a]

Inches to Millimeters

in.	mm
0.001	0.0254
0.005	0.127
0.01	0.254
1/64	0.397
3/32	2.381
0.1	2.54
7/64	2.778
2.165	54.991
4¼	107.95
18	457.2

[a] Conversion factor: 1 in. = 25.4 mm (exactly).

TABLE 11—PRESSURE AND STRESS EQUIVALENTS.[a]

Pounds-Force per Square Inch to Kilograms-Force per Square Millimeter[b]

psi	kgf/mm^2
1 000	0.7
57 000	40.0
74 000	52.0
85 000	60.0
102 000	71.7
120 000	84.4
125 000	88.0

[a] Conversion factors: 1 psi = 0.000 703 07 kgf/mm^2; 1 kgf = 9.80665 newtons (N).
[b] The metric unit of force in SI (Système International) units is the newton (N), which is defined as that force which, when applied to a body having a mass of one kilogram gives it an acceleration of one meter per second per second (1 m/s^2). A newton is equal approximately to ¼ lbf.

6.8 Approximate or nominal metric equivalents, usually whole numbers, should be used when the value to be converted is not critical, for example, nominal dimensions of a specimen or a machine. When the equivalent is approximate it should be so designated by including the abbreviation "approx" along with the equivalent (see 5.5.1.2). Nominal dimensions should show approximate equivalents. For example,

Determine the breaking load of a specimen 20 in. (approx 500 mm) long.
Use a CRT testing machine having a capacity of 10 lbf (approx 4.5 kgf).

Take individual specimens about 1 yd (1 m) long.
Cut a specimen approximately 4 by 6 in. (100 by 150 mm).

Note—A specimen *at least* 4 in. wide requires a width of *at least* 102 mm, not approx 100 mm.

6.9 The need for metric equivalents can be avoided in the case of tolerances if the limits are expressed in terms of per cent or percentage points, rather than absolute values.

6.10 The practical aspects of measuring must be considered when using metric equivalents. In measuring the length and width of an object, for example, the converted values should be no finer than the least division of the device used for making the original measurement. If a common rule (yardstick) divided into 1/16's of an inch is suitable for making the original measurements, a metric rule having a least division of 1 mm is obviously suitable for measuring the length and width in metric units and the equivalents should not be reported closer than the nearest millimeter. Similarly for smaller dimensions, such as thickness, a metric instrument having a least reading of 0.1 mm would be suitable when a special rule or vernier caliper is used for the original measurement. Analogous situations exist in weighing and electrical measurements.

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—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—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 5.4).

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 15). 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.

Three terms that may be encountered in the literature dealing with the modernized metric system are "metricize," "metrication," and "rationalize." These have been defined as follows:

Metricize—To convert any other unit to its metric equivalent. This may be an exact, a rounded, or a rationalized equivalent. For example, the classic 2 by 4 becomes 50.8 by 101.6 mm by exact conversion; 51 by 102 mm by rounding in accordance with 5. Rules for Conversion and Rounding, and 50 by 100 mm when rationalized.

Metrication—The act of converting any other unit to its metric equivalent.

Rationalize—To round completely a converted value to a popular standard figure compatible with noncritical mating components, interchangeable parts, or other nominal sizes in a series.

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 meter 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 meter 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 meter 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 centimeter-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 meter-kilogram-second (MKS) system. In 1935 Prof. 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 basic unit. This recommendation was accepted and in 1950 the ampere, the unit of electrical current, was established as a basic 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 a 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 additional improvements will be made in the future.

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 six 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 meter for length (l), kilogram (instead of the 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 $s = dl/dt$ (velocity), $a = ds/dt$ (acceleration), $f = ma$ (force), $w = fl$ (work or energy), $p = w/t$ (power). Some of these units have only generic names such as meter per second for velocity; others have special names such as the 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, chemical, or nuclear. A force of 1 newton applied for a distance of 1 meter produces 1 joule of heat, which is identical with what 1 watt of electric power produces in 1 second.

A2.7 Corresponding to the advantages of the SI system, 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 the 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 numerals. 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 the SI system 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 multiplied 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 six 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 meter. It is employed extensively by meteorologists. Another such unit is the gal (galileo) equal exactly to an acceleration of 0.01 meter per second^2. 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. The liter, used as a unit of fluid capacity, is not a member of the system. It was redefined in 1964 as equal to 0.001 cubic meter, exactly.

A2.12 Definitions of the six base and two supplementary units of the International System are given in the following paragraphs:

A2.12.1 *Meter*—The 11th CGPM (1960) adopted the meter (unit of length) as the length of exactly 1 650 763.73 wavelengths of the radiation in vacuum corresponding to the unperturbed transition between the levels $2p_{10}$ and $5d_5$ of the atom of krypton 86, the orange-red line. (This corresponds to a wavelength (krypton 86 orange-red) of $6\ 057.802 \times 10^{-10}$ m or 605.7802 nm.)

A2.12.2 *Kilogram*—The 3rd CGPM (1901) adopted the kilogram (unit of mass) as the mass of a particular cylinder of platinum-iridium alloy called the International Prototype Kilogram which is preserved in a vault at Sevres, France, by the International Bureau of Weights and Measures.

A2.12.3 *Second*—The 11th CGPM (1960) adopted the ephemeris second (unit of time) as exactly 1/31.556 925 974 7 of the tropical year of 1900, January, 0 days and 12 hours ephemeris time.[13]

A2.12.4 *Ampere*—The 9th CGPM (1948) adopted the ampere (unit of electric current) as the constant current that, if maintained in two straight parallel conductors of

[13] The 12th CGPM (1964) recommended the adoption of a new atomic frequency standard to define the second and empowered the International Committee on Weights and Measures to designate atomic or molecular standards of frequency as temporary standards. This standard is the transition between the hyperfine levels $F = 4$, $M = 0$ and $F = 3$, $M = 0$ of the fundamental state $^2S_{1/2}$ of the cesium-133 atom unperturbed by external fields. The value 9 192 631 770 hertz was assigned to the frequency of this transition.

infinite length, negligible circular cross sections, and placed 1 meter apart in a vacuum, will produce between these conductors a force equal to 2×10^{-7} newton per meter of length.

A2.12.5 *Degree Kelvin*—The 10th CGPM (1954) adopted the thermodynamic Kelvin degree (unit of temperature) as the unit of temperature determined by the Carnot cycle with the triple-point temperature of water defined as exactly 273.16°K.[14]

A2.12.6 *Candela*—The 9th CGPM (1948) adopted the candela (unit of luminous intensity) as a unit of such a value that the luminance of a full (blackbody) radiator at the freezing temperature of platinum is 60 candelas per square centimeter.

A2.12.7 *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.

A2.12.8 *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.

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 Electric charge	The *coulomb* is the quantity of electricity transported in one second by a current of one ampere.
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	The *volt* (unit of electric potential difference and electromotive force) is the difference of electric potential between two points of a conducting wire 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 one newton is displaced a distance of one meter in the direction of the force.

[14] The International Practical Kelvin Temperature Scale of 1960 and the International Practical Celsius Temperature Scale of 1960 are defined by a set of interpolation equations based on the following reference temperatures:

	deg K	deg C
Oxygen, liquid-gas equilibrium	90.18	−182.97
Water, solid-liquid equilibrium	273.15	0.00
Water, solid-liquid-gas equilibrium	273.16	0.01
Water, liquid-gas equilibrium	373.15	100.00
Zinc, solid-liquid equilibrium	692.655	419.505
Sulfur, liquid-gas equilibrium	717.75	444.6
Silver, solid-liquid equilibrium	1233.95	960.8
Gold, solid-liquid equilibrium	1336.15	1063.0

Physical Quantity	Unit and Definition
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 meter per second per second.
A2.13.8 Luminous flux	The *lumen* is the luminous flux emitted in a solid angle of one steradian by a uniform point source having an intensity of one candela.
A2.13.9 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.
A2.13.10 Power	The *watt* is the power which gives rise to the production of energy at the rate of one joule per second.

A3. CONVERSION FACTORS FOR PHYSICAL QUANTITIES[15]

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 of coherent "metric" units. Relationships which are exact in terms of the base units 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,

$$3.523\ 907\ \text{E}{-}02 \text{ is } 3.523\ 907 \times 10^{-2} \text{ or } 0.035\ 239\ 07.$$

Similarly,

$$3.386\ 389\ \text{E}{+}03 \text{ is } 3.386\ 389 \times 10^{3} \text{ or } 3\ 386.389.$$

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 5.3.

A3.3 *Organization:*

A3.3.1 The conversion factors are listed alphabetically and by physical quantity. The Alphabetical Listing contains only those units that have specific names; compounded units derived from the specific units are given in the Listing by Physical Quantities. The Listing by Physical Quantities emphasizes the more frequently-used units and contains both specific and compounded units.

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

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[15] Adopted from E. A. Mechtly (Ref. 16).

ALPHABETICAL LIST OF UNITS

To convert from	to	multiply by
abampere	ampere	1.000 000*E+01
abcoulomb	coulomb	1.000 000*E+01
abfarad	farad	1.000 000*E+09
abhenry	henry	1.000 000*E−09
abmho	mho	1.000 000*E+09
abohm	ohm	1.000 000*E−09
abvolt	volt	1.000 000*E−08
acre	meter²	4.046 856 E+03
ampere (international of 1948)	ampere	9.998 35 E−01
angstrom	meter	1.000 000*E−10
astronomical unit	meter	1.495 98 E+11
atmosphere (normal)	newton/meter²	1.013 250*E+05
atmosphere (technical = 1 kgf/cm²)	newton/meter²	9.806 650*E+04
bar	newton/meter²	1.000 000*E+05
barn	meter²	1.000 000*E−28
barrel (for petroleum, 42 gal)	meter³	1.589 873 E−01
British thermal unit (International Steam Table)[16]	joule	1.055 06 E+03
British thermal unit (mean)	joule	1.055 87 E+03
British thermal unit (thermochemical)	joule	1.054 350 E+03
British thermal unit (39 F)	joule	1.059 67 E+03
British thermal unit (60 F)	joule	1.054 68 E+03
bushel (U.S.)	meter³	3.523 907 E−02
caliber	meter	2.540 000*E−04
calorie (International Steam Table)	joule	4.186 8 E+00
calorie (mean)	joule	4.190 02 E+00
calorie (thermochemical)	joule	4.184 000*E+00
calorie (15 C)	joule	4.185 80 E+00
calorie (20 C)	joule	4.181 90 E+00
calorie (kilogram, International Steam Table)	joule	4.186 8 E+03
calorie (kilogram, mean)	joule	4.190 02 E+03
calorie (kilogram, thermochemical)	joule	4.184 000*E+03
carat (metric)	kilogram	2.000 000*E−04
Celsius (temperature)	Kelvin	$t_K = t_C + 273.15$
centigrade	see 4.3.1	
centimeter of mercury (0 C)	newton/meter²	1.333 22 E+03
centimeter of water (4 C)	newton/meter²	9.806 38 E+01
centipoise	newton second/meter²	1.000 000*E−03
circular mil	meter²	5.067 075 E−10
coulomb (international of 1948)	coulomb	9.998 35 E−01
cup	meter³	2.365 882 E−04
curie	disintegration/second	3.700 000*E+10

[16] This value has been adopted by ISO/TC 12 instead of the value 1.05504 E+03 used on the computation of the International Steam Table.

To convert from	to	multiply by
day (mean solar)	second (mean solar)	8.640 000*E+04
day (sidereal)	second (mean solar)	8.616 409 E+04
degree (angle)	radian	1.745 329 E−02
decibar	newton/meter	1.000 000*E+04
dyne	newton	1.000 000*E−05
electron volt	joule	1.602 10 E−19
EMU of capacitance	farad	1.000 000*E+09
EMU of current	ampere	1.000 000*E+01
EMU of electric potential	volt	1.000 000*E−08
EMU of inductance	henry	1.000 000*E−09
EMU of resistance	ohm	1.000 000*E−09
ESU of capacitance	farad	1.112 6 E−12
ESU of current	ampere	3.335 6 E−10
ESU of electric potential	volt	2.997 9 E+02
ESU of inductance	henry	8.987 6 E+11
ESU of resistance	ohm	8.987 6 E+11
erg	joule	1.000 000*E−07
Fahrenheit (temperature)	Celsius	$t_C = (t_F - 32)/1.8$
Fahrenheit (temperature)	Kelvin	$t_K = (t_F + 459.67)/1.8$
farad (international of 1948)	farad	9.995 05 E−01
faraday (based on carbon 12)	coulomb	9.648 70 E+04
faraday (chemical)	coulomb	9.649 57 E+04
faraday (physical)	coulomb	9.652 19 E+04
fathom	meter	1.828 800*E+00
fermi (femtometer)	meter	1.000 000*E−15
fluid ounce (U.S.)	meter^3	2.957 353 E−05
foot	meter	3.048 000*E−01
foot (U.S. survey)	meter	1200/3937*E+00
foot (U.S. survey)	meter	3.048 006 E−01
foot of water (39.2 F)	newton/meter^2	2.988 98 E+03
foot candle	lumen/meter^2	1.076 391 E+01
foot lambert	candela/meter^2	3.426 259 E+00
gal (galileo)	meter/second^2	1.000 000*E−02
gallon (U.K. liquid)	meter^3	4.546 087 E−03
gallon (U.S. dry)	meter^3	4.404 884 E−03
gallon (U.S. liquid)	meter^3	3.785 412 E−03
gamma	tesla	1.000 000*E−09
gauss	tesla	1.000 000*E−04
gilbert	ampere turn	7.957 747 E−01
gill (U.K.)	meter^3	1.420 652 E−04
gill (U.S.)	meter^3	1.182 941 E−04
grad	degree (angular)	9.000 000*E−01
grad	radian	1.570 796 E−02
grain (1/7000 lbm avoirdupois)	kilogram	6.479 891*E−05
gram	kilogram	1.000 000*E−03
henry (international of 1948)	henry	1.000 495 E+00
horsepower (550 ft·lbf/sec)	watt	7.456 999 E+02
horsepower (boiler)	watt	9.809 50 E+03
horsepower (electric)	watt	7.460 000*E+02
horsepower (metric)	watt	7.354 99 E+02
horsepower (water)	watt	7.460 43 E+02
horsepower (U.K.)	watt	7.457 0 E+02
hour (mean solar)	second (mean solar)	3.600 000*E+03
hour (sidereal)	second (mean solar)	3.590 170 E+03
hundredweight (long)	kilogram	5.080 235 E+01
hundredweight (short)	kilogram	4.535 924 E+01
inch	meter	2.540 000*E−02

To convert from	to	multiply by
inch of mercury (32 F)	newton/meter²	3.386 389 E+03
inch of mercury (60 F)	newton/meter²	3.376 85 E+03
inch of water (39.2 F)	newton/meter²	2.490 82 E+02
inch of water (60 F)	newton/meter²	2.488 4 E+02
joule (international of 1948)	joule	1.000 165 E+00
kayser	1/meter	1.000 000*E+02
Kelvin (temperature)	Celsius	$t_C = t_K - 273.15$
kilocalorie (International Steam Table)	joule	4.186 74 E+03
kilocalorie (mean)	joule	4.190 02 E+03
kilocalorie (thermochemical)	joule	4.184 000*E+03
kilogram force (kgf)	newton	9.806 650*E+00
kiolgram mass	kilogram	1.000 000*E+00
kilopond force	newton	9.806 650*E+00
kip	newton	4.448 222 E+03
knot (international)	meter/second	5.144 444 E−01
lambert	candela/meter²	$1/\pi$* E+04
lambert	candela/meter²	3.183 099 E+03
langley	joule/meter²	4.184 000*E+04
lbf (pound-force, avoirdupois)[17]	newton	4.448 222 E+00
lbm (pound-mass, avoirdupois)[18]	kilogram	4.535 924 E−01
light year	meter	9.460 55 E+15
liter (new)[19]	meter³	1.000 000*E−03
liter (old)[19]	meter³	1.000 028 E−03
lux	lumen/meter²	1.000 000*E+00
maxwell	weber	1.000 000*E−08
meter[20]	wavelengths Kr 86	1.650 764 E+06
micron	meter	1.000 000*E−06
mil	meter	2.540 000*E−05
mile (international nautical)	meter	1.852 000*E+03
mile (U.K. nautical)	meter	1.853 184*E+03
mile (U.S. nautical)	meter	1.852 000*E+03
mile (U.S. statute)	meter	1.609 344*E+03
millibar	newton/meter²	1.000 000*E+02
millimeter of mercury (0 C)	newton/meter²	1.333 224 E+02
minute (angle)	radian	2.908 882 E−04
minute (mean solar)	second (mean solar)	6.000 000*E+01
minute (sidereal)	second (mean solar)	5.983 617 E+01
moment of inertia (lbm·ft²)	kilogram-meter²	4.214 012 E−02
moment of inertia (lbm·in.²)	kilogram-meter²	2.926 397 E−05
moment of section[21] (second moment of area) (foot⁴)	meter⁴	8.630 975 E−03
moment of section[21] (second moment of area) (inch⁴)	meter⁴	4.162 314 E−07
month (mean calendar)	second (mean solar)	2.628 000*E+06
oersted	ampere/meter	7.957 747 E+01
ohm (international of 1948)	ohm	1.000 495 E+00
ounce force (avoirdupois)	newton	2.780 139 E−01
ounce mass (avoirdupois)	kilogram	2.834 952 E−02
ounce mass (troy or apothecary)	kilogram	3.110 348 E−02

[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.

[19] The General Conference on Weights and Measures (CGPM) in 1964 redefined the liter to be exactly 1000 cm^3. Hence, the term liter is no longer an acceptable metric unit and should be replaced by the cubic decimeter, expressed as 10^{-3} m^3, dm^3, or 1000 cm^3.

[20] The exact conversion factor is 1.650 763 73*E+06.

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

To convert from	to	multiply by
ounce (U.S. fluid)	meter^3	2.957 353 E−05
parsec	meter	3.083 74 E+16
pascal	newton/meter^2	1.000 000*E+00
peck (U.S.)	meter^3	8.809 768 E−03
pennyweight	kilogram	1.555 174 E−03
phot	lumen/meter^2	1.000 000*E+04
pica (printer's)	meter	4.217 518 E−03
pint (U.S. dry)	meter^3	5.506 105 E−04
pint (U.S. liquid)	meter^3	4.731 765 E−04
point (printer's)	meter	3.514 598*E−04
poise	newton·second/meter^2	1.000 000*E−01
poundal	newton	1.382 550 E−01
pound-force (lbf avoirdupois)[22]	newton	4.448 222 E+00
pound-mass (lbm avoirdupois)[23]	kilogram	4.535 924 E−01
pound-mass (troy or apothecary)	kilogram	3.732 417 E−01
quart (U.S. dry)	meter^3	1.101 221 E−03
quart (U.S. liquid)	meter^3	9.463 530 E−04
rad (radiation dose absorbed)	joule/kilogram	1.000 000*E−02
Rankine (temperature)	Kelvin	$t_K = t_R/1.8$
rhe	meter^2/newton-second	1.000 000*E+01
rod	meter	5.029 200*E+00
roentgen	coulomb/kilogram	2.579 760*E−04
second (angle)	radian	4.848 137 E−06
second (mean solar)	second (ephemeris)	consult American Ephemeris and Nautical Almanac
second (sidereal)	second (mean solar)	9.972 696 E−01
section	meter^2	2.589 988 E+06
section modulus (foot^3)	meter^3	2.831 685 E−02
section modulus (inch^3)	meter^3	1.638 706 E−05
shake	second	1.000 000*E−08
slug	kilogram	1.459 390 E+01
statampere	ampere	3.335 640 E−10
statcoulomb	coulomb	3.335 640 E−10
statfarad	farad	1.112 650 E−12
stathenry	henry	8.987 554 E+11
statmho	mho	1.112 650 E−12
stathom	ohm	8.987 554 E+11
statute mile (U.S.)	meter	1.609 344*E+03
statvolt	volt	2.997 925 E+02
stere	meter^3	1.000 000*E+00
stilb	candela/meter^2	1.000 000*E+04
stoke	meter^2/second	1.000 000*E−04
tablespoon	meter^3	1.478 676 E−05
teaspoon	meter^3	4.928 922 E−06
text	kilogram/meter	1.000 000*E−06
ton (assay)	kilogram	2.916 667 E−02
ton (long)	kilogram	1.016 047 E+03
ton (metric)	kilogram	1.000 000*E+03
ton (nuclear equivalent of TNT)	joule	4.20 E+09
ton (register)	meter^3	2.831 685 E+00
ton (short, 2000 lb)	kilogram	9.071 847 E+02
tonne	kilogram	1.000 000*E+03
torr (mm Hg, 0 C)	newton/meter^2	1.333 22 E+02
township	meter^2	9.323 957 E+07

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

To convert from	to	multiply by
tropical year 1900, Jan., day 0, hour 12[24]	second (ephemeris)	3.155 693 E+07
unit pole	weber	1.256 637 E−07
viscosity (stoke) (kinematic)	meter²/second	1.000 000*E−04
viscosity (poise) (absolute)	newton-second/meter²	1.000 000*E−01
viscosity (Saybolt):		
at 100 F	meter²/second at 311 K	4.635 E−06
at 210 F	meter²/second at 370 K	4.667 E−06
volt (international of 1948)	volt (absolute)	1.000 330 E+00
watt (international of 1948)	watt	1.000 165 E+00
yard	meter	9.144 000*E−01
year (calendar)	second (mean solar)	3.153 600*E+07
year (sidereal)	second (mean solar)	3.155 815 E+07
year (tropical)	second (mean solar)	3.155 693 E+07
year 1900, tropical, Jan., day 0, hour 12[25]	second (ephemeris)	3.155 693 E+07

CLASSIFIED LIST OF UNITS

Acceleration

foot/second²	meter/second²	3.048 000*E−01
free fall, standard	meter/second²	9.806 650*E+00
gal (galileo)	meter/second²	1.000 000*E−02
inch/second²	meter/second²	2.540 000*E−02

Area

acre	meter²	4.046 856 E+03
barn	meter²	1.000 000*E−28
circular mil	meter²	5.067 075 E−10
foot²	meter²	9.290 304*E−02
inch²	meter²	6.451 600*E−04
mile² (U.S. statute)	meter²	2.589 988 E+06
section	meter²	2.589 988 E+06
township	meter²	9.323 957 E+07
yard²	meter²	8.361 274 E−01

Bending Moment or Torque

dyne-centimeter	newton meter	1.000 000*E−07
kgf-meter	newton meter	9.806 650*E+00
lbf-inch	newton meter	1.129 848 E−01
lbf-foot	newton meter	1.355 818 E+00
ounce force-inch	newton meter	7.061 552 E−03

(Bending Moment or Torque)/Length

lbf-foot/inch	newton-meter/meter	5.337 866 E+01
lbf-inch/inch	newton-meter/meter	4.448 222 E+00

Capacity (See Volume)

Density (See Mass/Volume)

Electricity and Magnetism[26]

abampere	ampere	1.000 000*E+01
abcoulomb	coulomb	1.000 000*E+01
abfarad	farad	1.000 000*E+09

[24] The exact conversion factor is 3.155 692 597 47*E+07.
[25] The exact conversion factor is 3.155 692 597 47*E+07.
[26] ESU means electrostatic cgs unit. EMU means electromagnetic cgs unit.

To convert from	to	multiply by
abhenry	henry	1.000 000*E−09
abmho	mho	1.000 000*E+09
abohm	ohm	1.000 000*E−09
abvolt	volt	1.000 000*E−08
ampere (international of 1948)	ampere	9.998 35 E−01
ampere hour	coulomb	3.600 000*E+03
coulomb (international of 1948)	coulomb	9.998 35 E−01
EMU of capacitance	farad	1.000 000*E+09
EMU of current	ampere	1.000 000*E+01
EMU of electric potential	volt	1.000 000*E−08
EMU of inductance	henry	1.000 000*E−09
EMU of resistance	ohm	1.000 000*E−09
ESU of capacitance	farad	1.112 6 E−12
ESU of current	ampere	3.335 6 E−10
ESU of electric potential	volt	2.997 9 E+02
ESU of inductance	henry	8.987 6 E+11
ESU of resistance	ohm	8.987 6 E+11
farad (international of 1948)	farad	9.995 05 E−01
faraday (based on carbon 12)	coulomb	9.648 70 E+04
faraday (chemical)	coulomb	9.649 57 E+04
faraday (physical)	coulomb	9.652 19 E+04
gamma	tesla	1.000 000*E−09
gauss	tesla	1.000 000*E−04
gilbert	ampere-turn	7.957 747 E−01
henry (international of 1948)	henry	1.000 495 E+00
maxwell	weber	1.000 000*E−08
oersted	ampere/meter	7.957 747 E+01
ohm (international of 1948)	ohm	1.000 495 E+00
statampere	ampere	3.335 640 E−10
statcoulomb	coulomb	3.335 640 E−10
statfarad	farad	1.112 650 E−12
stathenry	henry	8.987 554 E+11
statmho	mho	1.112 650 E−12
statohm	ohm	8.987 554 E+11
statvolt	volt	2.997 925 E+02
unit pole	weber	1.256 637 E−07
volt (international of 1948)	volt	1.000 330 E+00

Energy (Includes Work)

British thermal unit (International Steam Table)[16]	joule	1.055 06 E+03
British thermal unit (mean)	joule	1.055 87 E+03
British thermal unit (thermochemical)	joule	1.054 350 E+03
British thermal unit (39 F)	joule	1.059 67 E+03
British thermal unit (60 F)	joule	1.054 68 E+03
calorie (International Steam Table)	joule	4.186 8 E+00
calorie (mean)	joule	4.190 02 E+00
calorie (thermochemical)	joule	4.184 000*E+00
calorie (15 C)	joule	4.185 80 E+00
calorie (20 C)	joule	4.181 90 E+00
calorie (kg, International Steam Table)	joule	4.186 8 E+03
calorie (kg, mean)	joule	4.190 02 E+03
calorie (kg, thermochemical)	joule	4.184 000*E+03
electron volt	joule	1.602 10 E−19
erg	joule	1.000 000*E−07

To convert from	to	multiply by
foot-pound-force	joule	1.355 818 E+00
foot-poundal	joule	4.214 011 E−02
joule (international of 1948)	joule	1.000 165 E+00
kilocalorie (International Steam Table)	joule	4.186 8 E+03
kilocalorie (mean)	joule	4.190 02 E+03
kilocalorie (thermochemical)	joule	4.184 000*E+03
kilowatt-hour	joule	3.600 000*E+06
kilowatt-hour (international of 1948)	joule	3.600 59 E+06
ton (nuclear equivalent of TNT)	joule	4.20 E+09
watt-hour	joule	3.600 000*E+03
watt-second	joule	1.000 000*E+00

Energy/Area Time

Btu (thermochemical)/foot^2 second	watt/meter^2	1.134 893 E+04
Btu (thermochemical)/foot^2 minute	watt/meter^2	1.891 488 E+02
Btu (thermochemical)/foot^2 hour	watt/meter^2	3.152 481 E+00
Btu (thermochemical)/inch^2 second	watt/meter^2	1.634 246 E+06
calorie (thermochemical)/centimeter^2 minute	watt/meter^2	6.973 333 E+02
erg/centimeter^2 second	watt/meter^2	1.000 000*E−03
watt/centimeter^2	watt/meter^2	1.000 000*E+04

Flow (See Mass/Time or Volume/Time)

Force

dyne	newton	1.000 000*E−05
kilogram-force	newton	9.806 650*E+00
kilopond-force	newton	9.806 650*E+00
kip	newton	4.448 222 E+03
ounce-force (avoirdupois)	newton	2.780 139 E−01
pound-force (lbf avoirdupois)[27]	newton	4.448 222 E+00
pound-force (lbf avoirdupois)[28]	kilogram-force[29]	4.535 924 E−01
poundal	newton	1.382 550 E−01

Force/Area (See Pressure)

Force/Length

pound-force/inch	newton/meter	1.751 268 E+02
pound-force/foot	newton/meter	1.459 390 E+01

Heat

Btu (thermochemical) in./sec ft^2 deg F (k, thermal conductivity)	watt/meter deg K	5.188 732 E+02
Btu (International Steam Table) in./sec ft^2 deg F (k, thermal conductivity)	watt/meter deg K	5.192 224 E+02
Btu (thermochemical) in./hr ft^2 deg F (k, thermal conductivity)	watt/meter deg K	1.441 314 E−01

[27] The exact conversion factor is 4.448 221 615 260 5*E+00.
[28] The exact conversion factor is 4.535 923 7*E−01.
[29] The metric unit of force, the newton, is approximately 1/10 kgf.

To convert from	to	multiply by
Btu (International Steam Table) in./hr ft² deg F (k, thermal conductivity)	watt/meter deg K	1.442 285 E−01
Btu (International Steam Table)/ft²	joule/meter²	1.135 657 E+04
Btu (thermochemical)/ft²	joule/meter²	1.134 893 E+04
Btu (International Steam Table)/ hr ft²/deg F (C, thermal conductance)	watt/meter² deg K	5.678 286 E+00
Btu (thermochemical)/hr ft² deg F (C, thermal conductance)	watt/meter² deg K	5.674 466 E+00
Btu (International Steam Table)/ pound mass	joule/kilogram	2.326 009 E+03
Btu (thermochemical)/pound mass	joule/kilogram	2.324 444 E+03
Btu (International Steam Table)/ lbm deg F (c, heat capacity)	joule /kg deg K	4.186 816 E+03
Btu (thermochemical)/lbm deg F (c, heat capacity)	joule/kg deg K	4.184 000 E+03
Btu (International Steam Table)/ sec ft² deg F	watt/meter² deg K	2.044 183 E+04
Btu (thermochemical)/sec ft² deg F	watt/meter² deg K	2.042 808 E+04
cal/cm²	joule/meter²	4.184 000*E+04
cal/cm² sec	watt/meter²	4.184 000*E+04
cal/cm sec deg C	watt/meter deg K	4.184 000*E+02
cal (International Steam Table)/g	joule/kilogram	4.186 737 E+03
cal (International Steam Table)/ g deg C	joule/kilogram deg K	4.186 737 E+03
cal (thermochemical)/g	joule/kilogram	4.184 000*E+03
cal (thermochemical)/g deg C	joule/kilogram deg K	4.184 000*E+03
deg F hr ft²/Btu (thermochemical) (R, thermal resistance)	deg K meter²/watt	1.762 280 E−01
deg F hr ft²/Btu (International Steam Table) (R, thermal resistance)	deg K meter²/watt	1.761 094 E−01
ft²/hr (thermal diffusivity)	meter²/second	2.580 640*E−05

Length

angstrom	meter	1.000 000*E−10
astronomical unit	meter	1.495 98 E+11
caliber	meter	2.540 000*E−04
fathom	meter	1.828 800*E+00
fermi (femtometer)	meter	1.000 000*E−15
foot	meter	3.048 000*E−01
foot (U.S. survey)	meter	1200/3937*E+00
foot (U.S. survey)	meter	3.048 006 E−01
inch	meter	2.540 000*E−02
league (international nautical)	meter	5.556 000*E+03
league (statute)	meter	4.828 032*E+03
league (U.K. nautical)	meter	5.559 552*E+03
light year	meter	9.460 55 E+15
micron	meter	1.000 000*E−06
mil	meter	2.540 000*E−05
mile (international nautical)	meter	1.852 000*E+03
mile (U.K. nautical)	meter	1.853 184*E+03

To convert from	to	multiply by
mile (U.S. nautical)	meter	1.852 000*E+03
mile (U.S. statute)	meter	1.609 344*E+03
parsec	meter	3.083 74 E+16
pica (printers)	meter	4.217 518 E−03
point (printers)	meter	3.514 598*E−04
rod	meter	5.029 200*E+00
statute mile (U.S.)	meter	1.609 344*E+03
yard	meter	9.144 000*E−01
LIGHT		
foot-candle	lumen/meter²	1.076 391 E+01
foot-candle	lux	1.076 391 E+01
foot-lambert	candela/meter²	3.426 3 E+00
lux	lumen/meter²	1.000 000*E+00
MASS		
carat (metric)	kilogram	2.000 000*E−04
gram	kilogram	1.000 000*E−03
hundredweight (long)	kilogram	5.080 235 E+01
hundredweight (short)	kilogram	4.535 924 E+01
kilogram-force second² meter (mass)	kilogram	9.806 650*E+00
kilogram-mass	kilogram	1.000 000*E+00
lbm (pound-mass avoirdupois)[30]	kilogram	4.535 924 E−01
ounce mass (avoirdupois)	kilogram	2.834 952 E−02
ounce mass (troy or apothecary)	kilogram	3.110 348 E−02
pennyweight	kilogram	1.555 174 E−03
pound-mass (lbm avoirdupois)[30]	kilogram	4.535 924 E−01
pound mass (troy or apothecary)	kilogram	3.732 417 E−01
slug	kilogram	1.459 390 E+01
ton (assay)	kilogram	2.916 667 E−02
ton (long, 2240 lbm)	kilogram	1.016 047 E+03
ton (metric)	kilogram	1.000 000*E+03
ton (short, 2000 lbm)	kilogram	9.071 847 E+02
tonne	kilogram	1.000 000*E+03
MASS/AREA		
ounce-mass/yard²	kilogram/meter²	3.390 574 E−02
pound-mass/ft²	kilogram/meter²	4.882 428 E+00
MASS/CAPACITY (SEE MASS/VOLUME)		
MASS/TIME (INCLUDES FLOW)		
pound-mass/second	kilogram/second	4.535 924 E−01
pound-mass/minute	kilogram/second	7.559 873 E−03
tons (short, mass)/hour	kilogram/second	2.519 958 E−01
MASS/VOLUME (INCLUDES DENSITY AND MASS CAPACITY)		
grain (lbm avoirdupois/7000)/ gal (U.S. liquid)	kilogram/meter³	1.711 806 E−02
grams/centimeter³	kilogram/meter³	1.000 000*E+03
lbm/foot³	kilogram/meter³	1.601 846 E+01
lbm/inch³	kilogram/meter³	2.767 991 E+04
ounces (avoirdupois)/gallon (U.K. liquid)	kilogram/meter³	6.236 027 E+00

[30] The exact conversion factor is 4.535 923 7*E−01.

To convert from	to	multiply by
ounces (avoirdupois)/gallon (U.S. liquid)	kilogram/meter^3	7.489 152 E+00
ounces (avoirdupois) (mass)/inch^3	kilogram/meter^3	1.729 994 E+03
pound-mass/gallon (U.K. liquid)	kilogram/meter^3	9.977 644 E+01
pound-mass/gallon (U.S. liquid)	kilogram/meter^3	1.198 264 E+02
slug/foot^3	kilogram/meter^3	5.153 79 E+02
tons (long, mass)/yard^3	kilogram/meter^3	1.328 939 E+03

POWER

To convert from	to	multiply by
Btu (International Steam Table)/hour	watt	2.930 667 E−01
Btu (thermochemical)/second	watt	1.054 350 E+03
Btu (thermochemical)/minute	watt	1.757 250 E+01
Btu (thermochemical)/hour	watt	2.928 751 E−01
calorie (thermochemical)/second	watt	4.184 000*E+00
calorie (thermochemical)/minute	watt	6.973 333 E−02
erg/second	watt	1.000 000*E−07
foot-pound force/hour	watt	3.766 161 E−04
foot-pound force/minute	watt	2.259 697 E−02
foot-pound force/second	watt	1.355 818 E+00
horsepower (550 ft·lbf/sec)	watt	7.456 999 E+02
horsepower (boiler)	watt	9.809 50 E+03
horsepower (electric)	watt	7.460 000*E+02
horsepower (metric)	watt	7.354 99 E+02
horsepower (water)	watt	7.460 43 E+02
horsepower (U.K.)	watt	7.457 0 E+02
kilocalorie (thermochemical)/minute	watt	6.973 333 E+01
kilocalorie (thermochemical)/second	watt	4.184 000*E+03
watt (international of 1948)	watt	1.000 165 E+00

PRESSURE OR STRESS (FORCE/AREA)

To convert from	to	multiply by
tmosphere (normal = 760 torr)	newton/meter^2	1.013 250*E+05
tmosphere (technical = 1 kgf/cm^2)	newton/meter^2	9.806 650*E+04
bar	newton/meter^2	1.000 000*E+05
centimeter of mercury (0 C)	newton/meter^2	1.333 22 E+03
centimeter of water (4 C)	newton/meter^2	9.806 38 E+01
decibar	newton/meter^2	1.000 000*E+04
dyne/centimeter^2	newton/meter^2	1.000 000*E−01
foot of water (39.2 F)	newton/meter^2	2.988 98 E+03
gram (force)/centimeter^2	newton/meter^2	9.806 650*E+01
inch of mercury (32 F)	newton/meter^2	3.386 389 E+03
inch of mercury (60 F)	newton/meter^2	3.376 85 E+03
inch of water (39.2 F)	newton/meter^2	2.490 82 E+02
inch of water (60 F)	newton/meter^2	2.488 4 E+02
kgf/centimeter^2	newton/meter^2	9.806 650*E+04
kgf/meter^2	newton/meter^2	9.806 650*E+00
kgf/millimeter^2	newton/meter^2	9.806 650*E+06
ksi	newton/meter^2	6.894 757 E+06
millibar	newton/meter^2	1.000 000*E+02
millimeter of mercury (0 C)	newton/meter^2	1.333 224 E+02
pascal	newton/meter^2	1.000 000*E+00
poundal per square foot	newton/meter^2	1.488 164 E+00
pound-force/foot^2	newton/meter^2	4.788 026 E+01

To convert from	to	multiply by
pound-force/inch² (psi)	newton/meter²	6.894 757 E+03
pound-force/inch² (psi)	kilograms-force/mm²[31]	7.030 696 E−04
psi	newton/meter²	6.894 757 E+03
torr (mm Hg, 0 C)	newton/meter²	1.333 22 E+02

SPEED (SEE VELOCITY)

STRESS (SEE PRESSURE)

TEMPERATURE

Celsius (temperature)	Kelvin	$t_K = t_C + 273.15$
Fahrenheit (temperature)	Kelvin	$t_K = (t_F + 459.67)/1.8$
Rankine (temperature)	Kelvin	$t_K = t_R/1.8$
Fahrenheit (temperature)	Celsius	$t_C = (t_F - 32)/1.8$
Kelvin (temperature)	Celsius	$t_C = t_K - 273.15$

TIME

day (mean solar)	second (mean solar)	8.640 000*E+04
day (sidereal)	second (mean solar)	8.616 409 E+04
hour (mean solar)	second (mean solar)	3.600 000*E+03
hour (sidereal)	second (mean solar)	3.590 170 E+03
minute (mean solar)	second (mean solar)	6.000 000*E+01
minute (sidereal)	second (mean solar)	5.983 617 E+01
month (mean calendar)	second (mean solar)	2.628 000*E+06
second (mean solar)	second (ephemeris)	consult American Ephemeris and Nautical Almanac
second (sidereal)	second (mean solar)	9.972 696 E−01
tropical year	second (ephemeris)	3.155 693 E+07
tropical year 1900, Jan., day 0, hour 12[32]	second (ephemeris)	3.155 693 E+07
year (calendar)	second (mean solar)	3.153 600*E+07
year (sidereal)	second (mean solar)	3.155 815 E+07
year (tropical)	second (mean solar)	3.155 693 E+07
year 1900, tropical, Jan., day 0, hour 12[32]	second (ephemeris)	3.155 693 E+07

TORQUE (SEE BENDING MOMENT)

VELOCITY (INCLUDES SPEED)

foot/hour	meter/second	8.466 667 E−05
foot/minute	meter/second	5.080 000*E−03
foot/second	meter/second	3.048 000*E−01
inch/second	meter/second	2.540 000*E−02
kilometer/hour[33]	meter/second	2.777 778 E−01
knot (international)	meter/second	5.144 444 E−01
mile/hour (U.S. statute)	meter/second	4.470 400*E−01
mile/minute (U.S. statute)	meter/second	2.682 240*E+01
mile/second (U.S. statute)	meter/second	1.609 344*E+03
mile/hour (U.S. statute)	kilometers/hour	1.609 344*E+00

VISCOSITY

centipoise	newton·second/meter²	1.000 000*E−03
centistoke	meter²/second	1.000 000*E−06

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[31] The metric unit of pressure or stress is the newton per square meter (N/m^2). 1 kgf/mm^2 is approximately 10^7 N/m^2 or 10 MN/m^2.

[32] The exact conversion factor is 3.155 692 597 47*E+07.

[33] Speedometers will read km/hr; metric unit is m/s.

To convert from	to	multiply by
$foot^2$/second	$meter^2$/second	9.290 304*E−02
poise	newton·second/$meter^2$	1.000 000*E−01
poundal-second/$foot^2$	newton·second/$meter^2$	1.488 164 E+00
pound mass/foot second	newton·second/$meter^2$	1.488 164 E+00
pound force second/$foot^2$	newton·second/$meter^2$	4.788 026 E+01
rhe	$meter^2$/newton·second	1.000 000*E+01
slug/foot-second	newton·second/$meter^2$	4.788 026 E+01
stoke	$meter^2$/second	1.000 000*E−04
viscosity (Saybolt):		
at 100 F	$meter^2$/second at 311 K	4.635 E−06
at 210 F	$meter^2$/second at 370 K	4.667 E−06

Volume (Includes Capacity)

acre-foot	$meter^3$	1.233 482 E+03
barrel (oil, 42 gal)	$meter^3$	1.589 873 E−01
board-foot	$meter^3$	2.359 737 E−03
bushel (U.S.)	$meter^3$	3.523 907 E−02
cup	$meter^3$	2.365 882 E−04
fluid ounce (U.S.)	$meter^3$	2.957 353 E−05
$foot^3$	$meter^3$	2.831 685 E−02
gallon (U.K.)	$meter^3$	4.546 087 E−03
gallon (U.S. dry)	$meter^3$	4.404 884 E−03
gallon (U.S. liquid)	$meter^3$	3.785 412 E−03
gill (U.K.)	$meter^3$	1.420 652 E−04
gill (U.S.)	$meter^3$	1.182 941 E−04
$inch^3$[34]	$meter^3$	1.638 706 E−05
liter (new)[19]	$meter^3$	1.000 000*E−03
liter (old)[19]	$meter^3$	1.000 028 E−03
ounce (U.K. fluid)	$meter^3$	2.841 305 E−05
ounce (U.S. fluid)	$meter^3$	2.957 353 E−05
peck (U.S.)	$meter^3$	8.809 768 E−03
pint (U.S. dry)	$meter^3$	5.506 105 E−04
pint (U.S. liquid)	$meter^3$	4.731 765 E−04
quart (U.S. dry)	$meter^3$	1.101 221 E−03
quart (U.S. liquid)	$meter^3$	9.463 530 E−04
stere	$meter^3$	1.000 000*E+00
tablespoon	$meter^3$	1.478 676 E−05
teaspoon	$meter^3$	4.928 922 E−06
ton (register)	$meter^3$	2.831 685 E+00
$yard^3$	$meter^3$	7.645 549 E−01

Volume/Time (Includes Flow)

cubic feet/minute	$meter^3$/second	4.719 474 E−04
cubic feet/second	$meter^3$/second	2.831 685 E−02
cubic inches/minute	$meter^3$/second	2.731 177 E−07
cubic yards/minute	$meter^3$/second	1.274 258 E−02
gallons (U.S. liquid)/day	$meter^3$/second	4.381 264 E−08
gallons (U.S. liquid)/minute	$meter^3$/second	6.309 020 E−05

Work (See Energy)

A4. Physical Constants

A4.1 The following lists of physical constants are recommended by the National Academy of Sciences and have been adopted by the National Bureau of Standards. The lists are taken from the National Bureau of Standards Technical News Bulletin, October 1963. The value for the first radiation constant c_1 was corrected to 3.7415 in the April 1965 NBS News Bulletin.

[34] The exact conversion factor is 1.638 706 4*E−05.

PHYSICAL CONSTANTS

Constant	Symbol	Value	Est.‡ error limit	Unit: Système International (MKSA)		Unit: Centimeter-gram-second (cgs)	
ADJUSTED VALUES OF CONSTANTS							
Speed of light in vacuum	c	2.997 925	3	$\times 10^{8}$	m s^{-1}	$\times 10^{10}$	cm s^{-1}
Elementary charge	e	1.602 10	7	10^{-19}	C	10^{-20}	cm$^{1/2}$g$^{1/2}$ *
		4.802 98	20	...	...	10^{-10}	cm$^{3/2}$g$^{1/2}$s^{-1} †
Avogadro constant	N_A	6.022 52	28	10^{23}	mol^{-1}	10^{23}	mol^{-1}
Electron rest mass	m_e	9.109 1	4	10^{-31}	kg	10^{-28}	g
		5.485 97	9	10^{-4}	u	10^{-4}	u
Proton rest mass	m_p	1.672 52	8	10^{-27}	kg	10^{-24}	g
		1.007 276 63	24	10^{0}	u	10^{0}	u
Neutron rest mass	m_n	1.674 82	8	10^{-27}	kg	10^{-24}	g
		1.008 665 4	13	10^{0}	u	10^{0}	u
Faraday constant	F	9.648 70	16	10^{4}	C mol^{-1}	10^{3}	cm$^{1/2}$g$^{1/2}$mol^{-1} *
		2.892 61	5	...	...	10^{14}	cm$^{3/2}$g$^{1/2}$s^{-1}mol^{-1} †
Planck constant	h	6.625 6	5	10^{-34}	J s	10^{-27}	erg s
	$\hbar$	1.054 50	7	10^{-34}	J s	10^{-27}	erg s
Fine structure constant	α	7.297 20	10	10^{-3}	...	10^{-3}	
	$1/\alpha$	1.370 388	19	10^{2}	...	10^{2}	
	$\alpha/2\pi$	1.161 385	16	10^{-3}	...	10^{-3}	
	α^2	5.324 92	14	10^{-5}	...	10^{-5}	
Charge to mass ratio for electron	e/m_e	1.758 796	19	10^{11}	C kg^{-1}	10^{7}	cm$^{1/2}$g$^{-1/2}$ *
		5.272 74	6	...	...	10^{17}	cm$^{3/2}$g$^{-1/2}$s^{-1} †
Quantum-charge ratio	h/e	4.135 56	12	10^{-15}	J s C^{-1}	10^{-7}	cm$^{3/2}$g$^{1/2}$s^{-1} *
		1.379 47	4	...	...	10^{-17}	cm$^{1/2}$g$^{1/2}$ †
Compton wavelength of electron	λ_C	2.426 21	6	10^{-12}	m	10^{-10}	cm
	$\lambda_C/2\pi$	3.861 44	9	10^{-13}	m	10^{-11}	cm
Compton wavelength of proton	$\lambda_{C,p}$	1.321 40	4	10^{-15}	m	10^{-13}	cm
	$\lambda_{C,p}/2\pi$	2.103 07	6	10^{-16}	m	10^{-14}	cm
Rydberg constant	R_∞	1.097 373 1	3	10^{7}	m^{-1}	10^{5}	cm^{-1}
Bohr radius	a_0	5.291 67	7	10^{-11}	m	10^{-9}	cm
Electron radius	r_e	2.817 77	11	10^{-15}	m	10^{-13}	cm
	r_e^2	7.939 8	6	10^{-30}	m^2	10^{-26}	cm^2
Thomson cross section	$8\pi r_e^2/3$	6.651 6	5	10^{-29}	m^2	10^{-25}	cm^2

Gyromagnetic ratio of proton	γ	2.675 19	2	10^{8}	rad $s^{-1}T^{-1}$	10^{4}	rad $s^{-1}G^{-1}$ *
	$\gamma/2\pi$	4.257 70	3	10^{7}	Hz T^{-1}	10^{3}	$s^{-1}G^{-1}$ *
(uncorrected for diamagnetism, H_2O)	γ'	2.675 12	2	10^{8}	rad $s^{-1}T^{-1}$	10^{4}	rad $s^{-1}G^{-1}$ *
	$\gamma'/2\pi$	4.257 59	3	10^{7}	Hz T^{-1}	10^{3}	$s^{-1}G^{-1}$ *
Bohr magneton	μ_B	9.273 2	6	10^{-24}	J T^{-1}	10^{-21}	erg G^{-1} *
Nuclear magneton	μ_N	5.050 5	4	10^{-27}	J T^{-1}	10^{-24}	erg G^{-1} *
Proton moment	μ_p	1.410 49	13	10^{-26}	J T^{-1}	10^{-23}	erg G^{-1} *
	μ_p/μ_N	2.792 76	7	10^{0}	...	10^{0}	
(uncorrected for diamagnetism, H_2O)	μ'_p/μ_N	2.792 68	7	10^{0}	...	10^{0}	
Anomalous electron moment correction	$(\mu_e/\mu_0)-1$	1.159 615	15	10^{-3}	...	10^{-3}	
Zeeman splitting constant	μ_B/hc	4.668 58	4	10^{1}	$m^{-1}T^{-1}$	10^{-5}	$cm^{-1}G^{-1}$ *
Gas constant	R	8.314 3	12	10^{0}	J °K^{-1} mol^{-1}	10^{7}	erg °K^{-1} mol^{-1}
Normal volume perfect gas	V_0	2.241 36	30	10^{-2}	m^3 mol^{-1}	10^{4}	cm^3 mol^{-1}
Boltzmann constant	k	1.380 54	18	10^{-23}	J °K^{-1}	10^{-16}	erg °K^{-1}
First radiation constant ($2\pi hc^2$)	c_1	3.741 5	3	10^{-16}	W m^2	10^{-5}	erg cm^2 s^{-1}
Second radiation constant	c_2	1.438 79	19	10^{-2}	m °K	10^{0}	cm °K
Wien displacement constant	b	2.897 8	4	10^{-3}	m °K	10^{-1}	cm °K
Stefan-Boltzmann constant	σ	5.669 7	29	10^{-8}	W m^{-2} °K^{-4}	10^{-5}	erg cm^{-2} s^{-1} °K^{-4}
Gravitational constant	G	6.670	15	10^{-11}	N m^2 kg^{-2}	10^{-8}	dyn cm^2 g^{-2}

Energy Conversion Factors

Electron-volt	eV	1.602 10	7	$\times 10^{-19}$	$J(eV)^{-1}$	$\times 10^{-12}$	erg $(eV)^{-1}$
Energy associated with:							
Unified atomic mass unit	c^2/Ne	9.314 78	15	10^{8}	eV u^{-1}	10^{8}	eV u^{-1}
Proton mass	m_pc^2/e	9.382 56	15	10^{8}	eV m_p^{-1}	10^{8}	eV m_p^{-1}
Neutron mass	m_nc^2/e	9.395 50	15	10^{8}	eV m_n^{-1}	10^{8}	eV m_n^{-1}
Electron mass	m_ec^2/e	5.110 06	5	10^{5}	eV m_e^{-1}	10^{5}	eV m_e^{-1}
Cycle	e/h	2.418 04	7	10^{14}	$Hz(eV)^{-1}$	10^{14}	$s^{-1}(eV)^{-1}$
Wavelength	ch/e	1.239 81	4	10^{-6}	eV m	10^{-4}	eV cm
Wave number	e/ch	8.065 73	23	10^{5}	$m^{-1}(eV)^{-1}$	10^{3}	$cm^{-1}(eV)^{-1}$
°K	e/k	1.160 49	16	10^{4}	°$K(eV)^{-1}$	10^{4}	°$K(eV)^{-1}$

‡ Based on 3 standard deviations; applied to last digits in preceding column.
* Electromagnetic system.
† Electrostatic system.
Abbreviations: C—coulomb; J—joule; Hz—hertz; W—watt; N—newton; T—tesla; G—gauss.

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) ASTM-IP Petroleum Measurement Tables D 1250
(4) Rec. Practice D 1914, Conversion Units and Factors Relating to Atmospheric Analysis
(5) Rec. Practices E 29, Designating Significant Places in Specified Limiting Values
(6) ASTM Metric Practice Guide, 1st Edition, Jan., 1964.

USA Standards Institute, 10 East 40th St., New York, N. Y. 10016

(7) Indian Standards Institution, Method for Precise Metric Conversion, (IS 1105, 1957)
(8) Indian Standards Institution, Guide for Specifying Metric Values (IS 1722, 1960)
(9) USA Standard Z10.1-1941, Abbreviations for Scientific and Engineering Terms.

International Organization for Standardization, Geneva, Switzerland, ISO Recommendation R 31 (available from USA Standards Institute):

(10) ISO/R 31/Part I—1956 (E), "Fundamental Quantities and Units of the MKSA System and Quantities and Units of Space and Time."
(11) ISO/R 31/Part II—1958 (E), "Quantities and Units of Periodic and Related Phenomena."
(12) ISO/R 31/Part III—1960 (E), "Quantities and Units of Mechanics."
(13) ISO/R 31/Part IV—"Quantities and Units of Heat."
(14) ISO/R 31/Part VI—"Quantities and Units of Light and Related Electro-Magnetic Radiations."

(15) "Unit of Weights and Measures (United States Customary and Metric): Definitions and Tables of Equivalents," NBS Misc. Publ. MP 233, Dec. 20, 1960. Available from Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. 20402.
(16) E. A. Mechtly, "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.
(17) J. F. Palmer, "The International System of Units Handbook," Brown Engineering Co., Inc., Huntsville, Ala.
(18) L. V. Judson, "Weights and Measures Standards of the United States, a Brief History," NBS Misc. Publ. 247, Oct. 1963.
(19) *Anon*, "Units and Systems of Weights and Measures. Their Origin, Development, and Present Status," NBS Letter Circ. LC 1035, Jan. 1960.
(20) L. V. Judson, "Units of Weight and Measure," NBS Misc. Publ. 233, Dec. 20, 1960.
(21) H. F. Stimson, "International Practical Temperature Scale of 1948," Text Revision of 1960, NBS Monograph 37, Sept. 8, 1961.
(22) F. B. Silsbee, "Systems of Electrical Units," NBS Monograph 56, Sept. 20, 1962.
(23) *Anon*, "Standards and Calibration," NBS Tech. News Bull., Vol 47, No. 2, Feb. 1963, p. 30.
(24) A. G. McNish, "Fundamentals of Measurement," *Electro-Technology*, Vol 71, No. 5, May 1963, pp. 113–128.
(25) *Anon*, "The New Values for the Physical Constants," NBS Tech. News Bull., Vol 47, No. 10, Oct. 1963, p. 175.
(26) *Anon*, "International System of Units—Resolution No. 12," NASA TT F-200, 1964.
(27) *Anon*, "NBS Adopts International System of Units," NBS Tech. News Bull., Vol 48, No. 4, April 1964, p. 61.

(28) A. G. McNish, "The International System of Units," *Materials Research & Standards*, Vol 5, No. 10, Oct. 1965.
(29) "Conversion Factors and Tables," British Standard 350, Part I, 1959.
(30) "Conversion Factors and Tables," British Standard 350, Part II, 1962.
(31) "Changing to the Metric System, Conversion Factors, Symbols, Definitions," Nat. Physical Lab., Her Majesty's Stationery Office, London, England, 1965.
(32) *Metric Standards for Engineering,* British Standard Handbook No. 18 (1966).

Handbooks containing conversion factors:

NOTE—Because of recent changes in the international definitions of some units, for example, the pound, yard, and international calorie, the conversion factors given in the handbooks may not be up to date; however, the differences would not affect significantly the conversion of values given in most publications.

(33) Handbook of Chemistry and Physics, 47th Edition, Chemical Rubber Publishing Co., Cleveland, Ohio, 1966–67.
(34) Kent's Mechanical Engineers' Handbook, 12th Edition, John Wiley and Sons, Inc., New York, N. Y. 10016, 1950.
(35) Lange's Handbook of Chemistry, 10th Edition, McGraw-Hill Book Co., Inc., New York, N. Y. 10036, 1961.
(36) Marks' Mechanical Engineers' Handbook, 6th Edition, McGraw-Hill Book Co., Inc., New York, N. Y. 10036, 1958.
(37) Perry's Chemical Engineers' Handbook, 3rd Edition, McGraw-Hill Book Co., Inc., New York, N. Y. 10036, 1950.
(38) O. T. Zimmerman and I. Lavine, *Conversion Factors and Tables*, 3rd Edition, Industrial Research Service Inc., Dover, N.H., 1961.

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