IEEE/ASTM SI 10™-2002
(Revision of
IEEE/ASTM SI 10-1997)

SI 10™

American National Standard for Use of the International System of Units (SI): The Modern Metric System

Co-Sponsors

ASTM Committee E43 on SI Practice

and

IEEE Standards Coordinating Committee 14
(Quantities, Units, and Letter Symbols)

IEEE

The Institute of Electrical and Electronics Engineers, Inc.
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Approved 26 July 2002
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Abstract: Guidance for the use of the modern metric system is given. Known as the International System of Units (abbreviated SI), the system is the basis for worldwide standardization of measurement units. Information is included on SI, a list of units recognized for use with SI, and a list of conversion factors, together with general guidance on proper style and usage.
Keywords: conversion factors, International System, International System of Units, metric practice, metric system, rounding, SI, Système International d'Unités

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Introduction

[This introduction is not a normative part of IEEE/ASTM SI 10-2002, American National Standard for Use of the International System of Units (SI): The Modern Metric System. It is provided for information only.]

This document, which supersedes IEEE/ASTM SI 10-1997, is the primary American National Standard for use of the International System of Units (SI). The first version of this standard was published by IEEE and ASTM in 1976. The sponsoring societies welcome comments and suggestions from interested individuals and organizations.

In 1988 the Metric Conversion Act was amended to designate “the metric system of measurement as the preferred system of weights and measures for United States trade and commerce.” With the increasing importance of the global marketplace, it has become imperative for U.S. industry to extend its use of SI and for U.S. citizens to gain a working knowledge of this modern metric system. This standard is intended to give authoritative information on SI and appropriate guidance concerning its application.

SI is defined in the document *Le Système International d’Unités,* published in French, with an English translation, by the International Bureau of Weights and Measures (BIPM). The BIPM was set up by the Convention du Mètre, signed in 1875 (see Annex D). *Le Système International d’Unités,* known informally as the “BIPM SI brochure,” is revised from time to time in accordance with the decisions of the General Conference on Weights and Measures (CGPM) and other international organizations. A U.S. version is published by NIST [B26].

IEEE/ASTM SI 10-2002 is consistent with the SI brochure in all matters that concern the SI itself, except that it presents the degree Celsius as simply another name for the kelvin that is used to express Celsius temperature, while the BIPM SI Brochure lists the degree Celsius as an SI derived unit. Of more practical importance is the difference in approach to non-SI units. IEEE/ASTM SI 10 and its predecessors have traditionally been more restrictive in their recommendations concerning the use of non-SI units. The SI Brochure, for example, lists the ångström as a unit that is “currently accepted for use with the International System,” and lists the cgs units and many others as units whose use “is not encouraged.” IEEE/ASTM SI 10, intended for the United States and developed under the consensus standardization process, makes the significantly stronger recommendation that these units are “not to be used.”

This standard was developed by the IEEE/ASTM Committee for Maintaining IEEE/ASTM SI 10, a joint committee established by the sponsoring organizations. The proposed standard generated by this joint committee was then formally adopted by IEEE and ASTM before transmission to the American National Standards Institute for approval as an American National Standard. At the time of the approval of this revision the joint committee had the following membership. Non-voting members at the time of publication are marked with an asterisk (*):

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Contents

American National Standard for Use of the International System of Units (SI): The Modern Metric System

1. Overview

The International System of Units is the form of the metric system that is generally in use around the world. This document gives guidance for the use of this system. It is the primary American National Standard for conformity to the International System of Units (or the SI, as it is abbreviated from its name in French, *Le Système International d'Unités*).

Any measurable quantity can be represented in this system with the aid of just seven "base" units, used directly for the quantities length, mass, time, electric current, temperature, amount of substance, and luminous intensity, or by combinations (called "derived" units) of these seven. For example, the unit of speed can be expressed by the unit of length divided by the unit of time. The SI is a complete and coherent system.

This standard shows first the two classes of units (base and derived) that make up the SI, together with the symbols by which they are known. Prefixes that allow the formation of decimal multiples and submultiples are explained. Then come notes on the proper use of the SI units and symbols in many applications.

In the first Annex are lists of many units from non-SI systems with the appropriate SI units that should be substituted and numerical conversion factors. Other annexes include rules for conversion and rounding, a discussion of the advantages of SI units with definitions where appropriate, a history of the development of the system, and a bibliography of source documents.

2. SI units and symbols

2.1 Classes of units

2.1.1 Base units

SI is built upon the seven well-defined base quantities of Table 1, which by convention are regarded as independent, and upon the seven base units for these quantities. The definitions of the base units are given in C.3. Note that in Table 1 and throughout this document the word "quantity" means a measurable attribute of a phenomenon or of matter.

Table 1—SI base units

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

2.1.2 Derived units

Derived units are formed by combining base units according to the algebraic relations linking the corresponding quantities. The symbols for derived units are obtained by means of the mathematical signs for multiplication, division, and use of exponents. Table 2 gives examples of derived units and shows how they are formed from base units.

Table 2—Examples of SI derived units expressed in terms of base units

Derived quantity	SI derived unit	
	Name	Symbol
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
wave number	reciprocal meter	m^{-1}
density, mass density	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
current density	ampere per square meter	A/m^2
magnetic field strength	ampere per meter	A/m
concentration (of amount of substance)	mole per cubic meter	mol/m^3
luminance	candela per square meter	cd/m^2

For convenience, certain derived units have been given special names and symbols. Those that are approved by the General Conference on Weights and Measures (abbreviated CGPM from its name in French; see Annex D), and are therefore formally part of the SI, are listed in Table 3. Definitions are provided in C.4.

Table 3—SI derived units with special names and symbols

Derived quantity	SI derived unit			
	Name	Symbol	Expressed in terms of other SI units	Expressed in terms of SI base units
angle, plane	radian	rad		$m \cdot m^{-1} = 1$
angle, solid	steradian	sr		$m^2 \cdot m^{-2} = 1$
frequency (of a periodic phenomenon)	hertz	Hz		s^{-1}
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$kg \cdot m^{-1} \cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C		$s \cdot A$
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2; $N/(A \cdot m)$	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
luminous flux	lumen	lm	$cd \cdot sr$	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	lux	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
activity (referred to a radionuclide)	becquerel	Bq		s^{-1}
absorbed dose, specific energy imparted, kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent, organ equivalent dose	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
catalytic activity	katal	kat		$mol \cdot s^{-1}$

It is sometimes convenient to express derived units in terms of other derived units with special names. Some examples appear in Table 3, and additional examples are given in Table 4. Note that while the expression of a derived unit in terms of the SI base units is unique, there are frequently alternative ways to express a derived unit using other derived units.

Table 4—Examples of SI derived units whose names include SI derived units with special names

Derived quantity	SI derived unit		
	Name	Symbol	Expressed in terms of SI base units
absorbed dose rate	gray per second	Gy/s	$m^2 \cdot s^{-3}$
angular acceleration	radian per second squared	rad/s^2	$m \cdot m^{-1} \cdot s^{-2} = s^{-2}$
angular velocity	radian per second	rad/s	$m \cdot m^{-1} \cdot s^{-1} = s^{-1}$
electric charge density	coulomb per cubic meter	C/m^3	$m^{-3} \cdot s \cdot A$
electric field strength	volt per meter	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric field strength	newton per coulomb	N/C	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric flux density	coulomb per square meter	C/m^2	$m^{-2} \cdot s \cdot A$
energy density	joule per cubic meter	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
entropy	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
exposure (x and gamma rays)	coulomb per kilogram	C/kg	$kg^{-1} \cdot s \cdot A$
heat capacity	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
heat flux density, irradiance	watt per square meter	W/m^2	$kg \cdot s^{-3}$
molar energy	joule per mole	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
molar entropy, molar heat capacity	joule per mole kelvin	$J/(mol \cdot K)$	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
moment of force	newton meter	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
permeability (magnetic)	henry per meter	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
permittivity	farad per meter	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^{-2}$
power density	watt per square meter	W/m^2	$kg \cdot s^{-3}$
radiance	watt per square meter steradian	$W/(m^2 \cdot sr)$	$kg \cdot s^{-3}$
radiant intensity	watt per steradian	W/sr	$m^2 \cdot kg \cdot s^{-3}$
specific heat capacity	joule per kilogram kelvin	$J/(kg \cdot K)$	$m^2 \cdot s^{-2} \cdot K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2 \cdot s^{-2}$
specific entropy	joule per kilogram kelvin	$J/(kg \cdot K)$	$m^2 \cdot s^{-2} \cdot K^{-1}$
surface tension	newton per meter	N/m	$kg \cdot s^{-2}$
surface tension	joule per square meter	J/m^2	$kg \cdot s^{-2}$
thermal conductivity	watt per meter kelvin	$W/(m \cdot K)$	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
viscosity, dynamic	pascal second	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
viscosity, kinematic	square meter per second	m^2/s	$m^2 \cdot s^{-1}$

2.1.3 Coherence

The SI base units and SI derived units form a coherent set, *the set of coherent SI units*, where "coherent" is used in the specialist sense of a system whose units are mutually related by rules of multiplication and division with no numerical factor other than 1.

2.2 SI prefixes

The prefixes listed in Table 5 are used to form decimal multiples and submultiples of the SI base and derived units. The term *SI units* includes the SI base units, the SI derived units, and all units formed from them using the SI prefixes.

2.2.1 Unit of mass

Among the base and derived units of SI, the unit of mass (kilogram) is the only one whose name, for historical reasons, contains a prefix. Names or symbols of decimal multiples and submultiples of the unit of mass are formed by attaching prefixes to the word gram or prefix symbols to the symbol g.

Table 5—SI prefixes

Multiplication factor	Name	Symbol
10^{24}	yotta	Y
10^{21}	zetta	Z
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
$10^{3} = 1000$	kilo	k
$10^{2} = 100$	hecto	h
$10^{1} = 10$	deka	da
$10^{-1} = 0.1$	deci	d
$10^{-2} = 0.01$	centi	c
$10^{-3} = 0.001$	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a
10^{-21}	zepto	z
10^{-24}	yocto	y

3. Use of the SI

3.1 General

SI is the form of the metric system that shall be used for all applications. It is important that this modern form of the metric system be thoroughly understood and properly applied. The remainder of this standard gives guidance concerning the use of the system, including the limited number of cases in which units outside SI are appropriately used, and makes recommendations concerning usage and style.

3.2 Application of SI prefixes

3.2.1 General

In general, use the SI prefixes (see 2.2) to indicate orders of magnitude. Thus, one can eliminate nonsignificant digits (for example, 12 300 m becomes 12.3 km) and leading zeros in decimal fractions (for example, 0.001 23 µm becomes 1.23 nm). SI prefixes provide a convenient alternative to the powers-of-ten notation (for example, 12.3×10^3 m becomes 12.3 km). Never use a prefix alone.

3.2.2 Selection

When expressing a quantity by a numerical value and a unit, give preference to a prefix that yields a numerical value between 0.1 and 1000. For simplicity, give preference to prefixes representing 1000 raised to a positive or negative integral power. However, the following factors may justify deviation from these prefixes:

a) In expressing area and volume, the prefixes hecto, deka, deci, and centi may be required; for example, cubic decimeter, square hectometer, cubic centimeter.
b) In tables of values of the same quantity, or in a discussion of such values within a given context, it is preferable to use the same unit multiple or submultiple throughout.
c) For certain quantities in particular applications, one particular multiple or submultiple is often used. For example, the millimeter is used for linear dimensions in engineering drawings even when the values lie far outside the range of 0.1 mm to 1000 mm; the centimeter is usually used for body measurements and clothing sizes.

3.2.3 Compound prefixes

Do not use prefixes formed by the juxtaposition of two or more SI prefixes. For example, use

1.3 nm, *not* 1.3 mµm

2.4 pF, *not* 2.4 µµF

3.2.4 Powers of units

An exponent attached to a unit symbol containing a prefix indicates that the multiple or submultiple of the unit (the unit with its prefix) is raised to the power expressed by the exponent.

Examples:

$1\ \mathrm{cm}^3 = (10^{-2}\ \mathrm{m})^3 = 10^{-6}\ \mathrm{m}^3$

$2.5\ \mathrm{ns}^{-1} = 2.5(10^{-9}\ \mathrm{s})^{-1} = 2.5 \times 10^9\ \mathrm{s}^{-1}$

$7\ \mathrm{mm}^2/\mathrm{s} = 7(10^{-3}\ \mathrm{m})^2/\mathrm{s} = 7 \times 10^{-6}\ \mathrm{m}^2/\mathrm{s}$

3.2.5 Prefixes defined as powers of two

In the computer field the SI prefixes kilo, mega, giga, etc. have sometimes been defined as powers of two. That is, kilo has been used to mean 1024 (i.e., 2^{10}), mega has been used to mean 1 048 576 (i.e., 2^{20}), etc. The SI prefixes shall not be used as prefixes for binary multiples.[1]

3.3 Other units

3.3.1 Units from other systems

To preserve the advantages of SI, minimize the use of non-SI units. Such use should be limited to units listed in Table 6 and Table 7.

Table 6—Units in use with SI

Quantity	Unit	Symbol	Value in SI units
time	minute	min	min = 60 s
	hour	h	h = 60 min = 3600 s
	day	d	d = 24 h = 86 400 s
plane angle	degree[a]	°	1° = (π /180) rad
	minute[a]	′	1′ = (1/60)° = (π /10 800) rad
	second[a]	″	1″ = (1/60)′ = (π /648 000) rad
	revolution, turn	r	r = 2π rad
area	hectare	ha	ha = 1 $\mathrm{hm}^2 = 10^4\ \mathrm{m}^2$
volume	liter[b]	L	L = 1 $\mathrm{dm}^3 = 10^{-3}\ \mathrm{m}^3$
mass	metric ton	t	t = 1 Mg = 10^3 kg

[a] Decimal degrees should be used for division of degrees, except for fields such as astronomy and cartography.

[b] See 3.3.2.4.

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[1] The International Electrotechnical Commission (IEC) has adopted prefixes for binary multiples in International Standard IEC 60027-2, Second edition, 2000-11, *Letter symbols to be used in electrical technology—Part 2: Telecommunications and electronics*. The names and symbols for the prefixes corresponding to 2^{10}, 2^{20}, 2^{30}, 2^{40}, 2^{50}, and 2^{60} are, respectively: kibi, Ki; mebi, Mi; gibi, Gi; tebi, Ti; pebi, Pi; and exbi, Ei. Thus, for example, one kibibyte would be written

1 KiB = 2^{10} B = 1024 B.

Although these prefixes are not part of the SI, they should be used in the field of information technology when needed to avoid the incorrect usage of SI prefixes.

Table 7—Units whose values are obtained experimentally

Quantity	Unit	Symbol	Value in SI units[a]
energy	electronvolt[b]	eV	eV = 1.602 176 462(63) × 10^{-19} J
mass	unified atomic mass unit[c]	u	u = 1.660 538 73(13) × 10^{-27} kg

[a] The numerical values are taken from Mohr and Taylor [B30]. The values are given with their combined standard uncertainties, which apply to the last two digits, shown in parentheses.

[b] The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum.

[c] The unified atomic mass unit is equal to 1/12 of the mass of an unbound atom of the nuclide ^{12}C, at rest, and in its ground state.

3.3.2 Units in use with SI

Compliance with this standard includes the use, as needed and convenient, of certain non-SI units listed in Table 6 and Table 7, as well as all the SI units, including the multiples and submultiples.

3.3.2.1 Time

The SI unit of time is the second (s), which should be used in technical calculations. However, where time relates to life customs or calendar cycles, the minute, hour, day, and other calendar units may be used. For example, vehicle speed is often expressed in the unit kilometer per hour (km/h).

3.3.2.2 Plane angle

The SI unit of plane angle is the number 1, which is also called by its special name radian (rad). Use of the degree and its decimal submultiples is permissible when the radian is not a convenient unit. Do not use the minute and second except for special fields such as astronomy and cartography.

3.3.2.3 Area

The SI unit of area is the square meter (m^2). The hectare (ha) is a special name for the square hectometer (hm^2). Large land or water areas are generally expressed in hectares or in square kilometers (km^2). Because hectare, for historical reasons, already involves an SI prefix, additional SI prefixes may not be used with this unit.

3.3.2.4 Volume

The SI unit of volume is the cubic meter (m^3). Use this unit, or a multiple or submultiple of it, such as cubic kilometer (km^3), cubic centimeter (cm^3), etc. The liter is a special name for the cubic decimeter (dm^3). SI prefixes are often used with liter for convenience.

In 1979, the CGPM approved the letters l and L as alternative symbols for the liter. Because the letter symbol l can easily be confused with the numeral 1, the symbol L is recommended for use in the U.S. The script “ell” (ℓ) shall not be used as a symbol for liter. See C.2 for information concerning the history of this unit.

3.3.2.5 Mass

The SI unit of mass is the kilogram (kg). This unit, or a multiple or submultiple formed by attaching an SI prefix to gram (g), is preferred in all applications.

The name “ton” has been given to several large mass units that are widely used in commerce and technology: the long ton of 2240 lb, the short ton of 2000 lb, and the metric ton of 1000 kg or 1 Mg, which is almost 2205 lb. “Tonne” is a name for metric ton that is used in many countries. Only the megagram is SI.

3.3.2.6 Units whose values are obtained experimentally

Table 7 lists two non-SI units that are also accepted for use with SI, whose values expressed in SI units must be obtained by experiment and are therefore not known exactly. These units are in common use in certain specialized fields.

3.3.3 Units and names that are not to be used

Table 8 lists units and names that are not to be used and gives SI equivalents that should be used in their place. These are examples of several metric and related units other than those of SI that have been defined over the years. Some are used only in special fields; others have found broad application outside the U.S. Do not use units that are not part of SI (or non-SI names for multiples or submultiples of SI units, such as micron for micrometer). Some units that are not to be used are discussed in more detail in 3.3.3.1 and 3.3.3.2. Note that these subsections and Table 8 are not complete but only indicate prominent examples.

3.3.3.1 Pressure and stress

The SI unit of pressure and stress is the pascal (newton per square meter), and with appropriate SI prefixes it should be used in all applications (see also 3.4.7). Do not use old metric units for pressure and stress such as kilogram-force per square centimeter (kgf/cm^2), or other non-SI units, such as torr, millimeter of mercury, or meter of water for pressure. One bar equals 100 kPa; the millibar (100 Pa) should be called by its SI name, the hectopascal (hPa).

3.3.3.2 Centimeter-gram-second (cgs) units

Prior to the introduction of the SI, many units were defined in measurement systems based upon the centimeter, gram, and second (“cgs units”) and given special names. Do not use any of these units.

A few examples of cgs units with special names that are not to be used are:

- In mechanics and fluid mechanics: erg, dyne, gal, poise, stokes
- In photometry: stilb, phot, lambert

In electricity and magnetism the so-called electrostatic units (esu) and electromagnetic units (emu) are further examples of cgs units. Do not use any of the units in these systems, including those with special names such as gauss, maxwell, oersted, gilbert, biot, and franklin. This prohibition extends also to those units with names formed with the prefixes “ab” and “stat,” such as the abampere and the statvolt.

These and other examples of units not to be used can be found in Table 8.

Table 8—Examples of unit names and symbols that are not to be used

Do not use		Value in SI units
Name	**Symbol**	
ångström	Å	Å = 0.1 nm = 10^{-10} m
are	a	a = dam^2 = 100 m^2
atmosphere, standard	atm	atm = 101.325 kPa
atmosphere, technical	at	at = 98.0665 kPa
bar	bar	bar = 100 kPa
barn	b	b = 100 fm^2 = 10^{-28} m^2
calorie (physics)[a]	cal	cal = 4.184 J
Calorie (nutrition)[a]	Cal	Cal = 4.184 kJ
candle		cd
candlepower	cp	cp = cd
dyne	dyn	dyn = 10^{-5} N
erg	erg	erg = 10^{-7} J
fermi	fermi	fermi = fm = 10^{-15} m
G, *g* (as a unit)		9.806 65 $\mathrm{m/s^2}$
gal	Gal	Gal = $\mathrm{cm/s^2}$ = 10^{-2} $\mathrm{m/s^2}$
gamma	γ	γ = nT = 10^{-9} T
gauss	G	G = 10^{-4} T
gon, grad, grade	gon	gon = (π/200) rad
kilocalorie[a]	kcal	kcal = 4.184 kJ
kilogram-force	kgf	kgf = 9.806 65 N
langley	$\mathrm{cal/cm^2}$	$\mathrm{cal/cm^2}$ = 41.84 $\mathrm{kJ/m^2}$ = 4.184×10^4 $\mathrm{J/m^2}$
maxwell	Mx	Mx = 10^{-8} Wb
metric carat		carat = 200 mg = 2×10^{-4} kg
metric horsepower		735.5 W
micron	m	μ = μm = 10^{-6} m
millimeter of mercury[b]	mmHg	mmHg ≈ 133.3 Pa
millimeter, centimeter, or meter of water[b]	$\mathrm{mmH_2O}$, etc.	9.806 65 Pa, etc.
millimicron	mμ	mμ = nm = 10^{-9} m
mho	mho	mho = S

Table 8—Examples of unit names and symbols that are not to be used (continued)

Do not use		Value in SI units
Name	Symbol	
oersted	Oe	Oe = (1000/4π) A/m
phot	ph	ph = 10^4 lx
poise	P	P = dyn · s/cm^2 = 0.1 Pa · s
stere	st	st = m^3
stilb	sb	sb = cd/cm^2 = 10^4 cd/m^2
stokes	St	St = cm^2/s = 10^{-4} m^2/s
torr	Torr	Torr = (101 325/760) Pa
x unit		1.0021×10^{-13} m
γ (mass)	γ	γ = μg = 10^{-9} kg
λ (volume)	λ	λ = mm^3 = 10^{-9} m^3

[a] See note [3] in Table A.1 for a note on the calorie and kilocalorie.
[b] See note [2] in Table A.1 for a note on the actual pressure corresponding to the height of a column of fluid.

3.4 Some comments concerning quantities and units

3.4.1 Mass, force, and weight

For a discussion of the treatment of these and related quantities in SI, see C.6.

3.4.2 Temperature

The SI unit of thermodynamic temperature is the kelvin (K). Use this unit to express thermodynamic temperature and temperature intervals. Wide use is also made of the degree Celsius (°C), which is equal to the unit kelvin. Degree Celsius is a special name for expressing Celsius temperature and temperature intervals. Celsius temperature t (which replaced centigrade temperature) is related to thermodynamic temperature T by the equation

$$t = T - T_0, \text{ where } T_0 = 273.15 \text{ K by definition.}$$

In practice, the International Temperature Scale of 1990 (ITS-90) [B29][2] serves as the basis for high-accuracy temperature measurements in science and technology.

3.4.3 Nominal dimensions

Many dimensions used to identify commercial products are nominal values—values like “2 × 4” lumber and one-inch pipe that exist in name only and are used for the purposes of convenient designation. Others, like the inch-based trade sizes of nuts and bolts, designate precisely one of the critical dimensions of the product. Although individuals should not convert such designations into SI units, trade associations and other organizations that are responsible for standardizing such products may adopt, without changing the product,

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[2] The numbers in brackets refer to the bibliography in Annex E.

nominal metric designations as deemed appropriate. (Note that the term “dimension” as used in this paragraph is defined in B.1.4 and differs from its use in 3.4.8.)

3.4.4 Quantities and units used in rotational mechanics

3.4.4.1 Angle, angular velocity, and angular acceleration

The coherent SI unit of plane angle is the number one; thus the coherent SI units of the quantities angle, angular velocity, and angular acceleration are, respectively, 1, 1/s, and $1/s^2$. However, it is often convenient to use the special name “radian” (rad), instead of the number 1 when expressing the values of these quantities. Thus, for clarity, the units rad, rad/s, and rad/s^2 are usually used, as shown in Table 4. Similar comments apply to solid angle; its coherent SI unit is also the number 1, which has the special name “steradian” (sr).

3.4.4.2 Moment of force (bending moment)

Because moment of force (bending moment), or torque, is equal to a force times a length (moment arm or lever arm), its SI unit is N · m. The joule (J), which is a special name for the SI unit of energy and work, shall not be used as a name for the unit of moment of force or of torque. (See also 3.4.5.)

3.4.4.3 Moment of inertia

Moment of inertia (I) is a property of the mass distribution of a body about an axis ($I = \sum mr^2$); its SI unit is $kg \cdot m^2$.

3.4.4.4 Angular momentum

Angular momentum (moment of momentum) is linear momentum (SI unit kg · m/s) times moment arm; its SI unit is $kg \cdot m^2/s$. The total angular momentum of a body of moment of inertia I (SI unit $kg \cdot m^2$) rotating with angular velocity ω (SI unit 1/s) is $I\omega$ (SI unit $kg \cdot m^2/s$).

3.4.4.5 Rotational kinetic energy

The kinetic energy of a body of moment of inertia I (SI unit $kg \cdot m^2$) rotating with angular velocity ω (SI unit 1/s) is $I\omega^2/2$; its SI unit is J.

3.4.4.6 Rotational work

The work done by a moment of force or by a torque (SI unit N · m) in a rotation through an angle (SI unit 1) is moment of force or torque times angle of rotation; its SI unit is J.

Note that if the unit of rotational work is written as N · m rather than as J, possible confusion may occur because in this form it appears identical to the unit of moment of force or torque. In vector algebraic expressions or vector diagrams, the distinction between work and moment of force or torque is obvious because work is the scalar product of force and displacement while moment of force or torque involves the vector product of moment arm and force, but no such distinction is possible in the associated units.

3.4.5 Energy and power

3.4.5.1 Energy

The coherent SI unit of energy, the joule, together with its multiples and submultiples, is preferred for all applications. The kilowatthour is widely used as a measure of electrical energy, but this unit shall not be introduced into any new fields.

3.4.5.2 Power

Use the coherent SI unit of power, the watt, together with its multiples and submultiples, for all applications involving the rate of transfer of energy. Do not use the megajoule per hour.

3.4.6 Impact energy absorption

This quantity, often incorrectly called "impact resistance" or "impact strength," is measured in terms of work required to break a standard specimen; the SI unit is the joule.

3.4.7 Pressure and vacuum

Gage pressure is absolute pressure minus ambient pressure (usually atmospheric pressure). Both gage pressure and absolute pressure are expressed in pascals, using SI prefixes as appropriate. Gage pressure is positive if above ambient pressure and negative if below. Pressure below ambient is often called vacuum; if the term "vacuum" is applied to a numerical measure it should be made clear whether absolute pressure or negative gage pressure is meant. See 3.5.5 for methods of designating gage pressure and absolute pressure.

3.4.8 Quantities expressed as pure numbers

Certain so-called dimensionless quantities, as for example refractive index, relative permeability, relative mass density, or the friction factor, are defined as the ratio of two comparable quantities. Such quantities have a dimensional product—or dimension—equal to 1 and are therefore expressed by pure numbers. The coherent SI unit is then the ratio of two identical SI units and may be expressed by the number one (for example, m/m = 1). More generally, a quantity of dimension one may be expressed by the ratio of units (for example, mm/m = 10^{-3}). The number one is generally not written out explicitly when a quantity of dimension one is expressed numerically.

The percent symbol (%) may be used for the number 0.01. Avoid, however, the abbreviations ppm for parts per million and ppb for parts per billion. Because the meanings of the words *billion, trillion,* etc. are not uniform worldwide, do not use terms such as parts per billion and parts per trillion. (See 3.5.4.3.)

When expressing the values of quantities of dimension one, the meaning has to be clear. Expressions like "The mass fraction of Pb in the sample is 90% (or 0.9)," or "the amount-of-substance fraction of Pb in the sample is 2.7×10^{-3}," are permissible; but they would not be permissible if the words "mass" and "amount of substance," respectively, were not in the two expressions. These two fractions can also be expressed as 0.9 kg/kg and 2.7 mmol/mol, respectively, which are more understandable and, therefore, preferred.

3.5 Style and usage

3.5.1 Rules for writing unit symbols

In SI, symbols represent units, such as m for meter. Unit symbols are written according to rules that have been standardized internationally.

a) Print unit symbols in roman (upright) type regardless of the type style used in the surrounding text. Most unit symbols are written in lower case (for example, m for meter). However, if the name of the unit is derived from a proper name, the first letter of the symbol is a capital (for example, W for watt, Pa for pascal). When the name of a unit is spelled out, it is always written in lowercase, except when the name is the first word of a sentence or is the name "degree Celsius." Prefix symbols use either lowercase or uppercase letters as shown in Table 5. Unit symbols retain their prescribed form (roman type, upper and lower case) regardless of the surrounding typography.

b) Do not alter unit symbols in the plural.

c) Do not follow unit symbols by a period except when used at the end of a sentence.

d) If the value of a quantity is expressed as a numerical value and a unit symbol, a space shall be left between them. For example, write 35 mm, *not* 35mm, 2.37 lm (for 2.37 lumens), *not* 2.37lm, and 20 °C, *not* 20°C.

EXCEPTION—No space is left between the number and the symbols for degree, minute, and second of plane angle.

e) Do not leave any space between the prefix and unit symbols.

f) Use symbols, not informal abbreviations, for units. For example, use “A,” and not “amp,” for ampere.

3.5.2 Rules for writing unit names

The handling of unit names varies internationally because of language differences. (See C.5 regarding spelling.) The following rules should be followed in the U.S.:

a) Spelled-out unit names are treated as common nouns in English. Thus, the first letter of a unit name is not capitalized except at the beginning of a sentence or in capitalized material such as a title.

b) Use plurals as required by the rules of English grammar, for example, henries for the plural of henry. The following plurals are irregular:

Singular	Plural
lux	lux
hertz	hertz
siemens	siemens

c) Use the plural when values exceed unity; otherwise use the singular (e.g., 1.1 meters, 0.9 meter).

d) Do not leave a space or place a hyphen between the prefix and unit name.

In three cases, the final vowel in the prefix is omitted: “megohm,” “kilohm,” and “hectare.” In all other cases where the unit name begins with a vowel, both vowels are retained and both are pronounced.

3.5.3 Units formed by multiplication and division

3.5.3.1 Unit names

a) *Product*. Use a space (preferred) or a hyphen:

newton meter or newton-meter

In the case of the watt hour the space may be omitted, thus:

watthour

b) *Quotient*. Use the word “per” and not a solidus:

meter per second, *not* meter/second

c) *Powers*. Use the modifier “squared” or “cubed” placed after the unit name:

meter per second squared

In the case of area or volume, a modifier may be placed before the unit name:

square millimeter, cubic meter, watt per square meter

d) *Symbols*. To avoid ambiguity in complicated expressions, unit symbols are preferred over unit names.

e) *Plurals*. To form the plural of a unit that is formed by multiplication of other units, use the plural form of the last unit in the product; for example, newton meters, pascal seconds. If a quotient is involved, the last unit in the numerator is made plural; for example, meters per second squared; kelvins per watt; kelvin meters per watt.

3.5.3.2 Unit symbols

The symbol for a compound unit that is the product of two or more units is indicated by either a raised dot, which is preferred, or by a space; thus, for newton meter

$\mathrm{N \cdot m}$ or $\mathrm{N\ m}$

For limited character sets where the raised dot is not possible, use a space or a dot on the line. In the case of kilowatthour (a non-SI unit), the symbol kWh is permitted.

The symbol for a compound unit that is a *quotient* of two or more units is indicated in one of the following ways:

$\mathrm{m/s}$ *or* $\mathrm{m \cdot s^{-1}}$ *or* $\frac{\mathrm{m}}{\mathrm{s}}$

Do not use a solidus followed by a multiplication sign or by a division sign on the same line unless ambiguity is avoided by parentheses. In complicated cases, use negative exponents or parentheses to avoid ambiguity. For example, write

$\mathrm{J/(mol \cdot K)}$ *or* $\mathrm{J \cdot mol^{-1} \cdot K^{-1}}$ *or* $\mathrm{(J/mol)/K}$, but *not* $\mathrm{J/mol/K}$

3.5.3.3 Mixtures

Do not mix symbols and unit names in the same expression. For example, write

joules per kilogram *or* J/kg

Do not write

joules/kilogram *or* joules/kg *or* joules $\cdot$ kg^{-1}

3.5.4 Numbers

3.5.4.1 Decimal marker

In the U.S., the decimal marker is a dot on the line. When writing numbers between one and minus one, write a zero before the decimal marker.

3.5.4.2 Grouping digits

Outside the U.S., the comma is widely used as the decimal marker. In some applications, therefore, the common practice in the U.S. of using the comma to separate digits into groups of three (as in 23,478) may cause ambiguity. To avoid this source of confusion, international practice calls for separating the digits into groups of three, counting from the decimal marker toward the left and the right, and using a thin, fixed space to separate the groups. In numbers of four digits on either side of the decimal marker the space is usually not necessary, except for uniformity in tables.

Examples: 2.141 596 73 722 7372 0.1334

Where this practice is followed, the width of the space should be constant even if, as is often the case in printing, justified spacing is used between words. In certain special applications, such as in engineering drawings and financial statements, the practice of inserting spaces into separate groups of numbers is not customary.

3.5.4.3 Billion

Because billion means a thousand million (prefix giga) in the U.S. but a million million (prefix tera) in some other countries, do not use the term and similar terms for larger numbers in technical writing.

3.5.4.4 Roman numerals

Do not use M to indicate thousands (as in MCF for thousands of cubic feet or in MCM for thousands of circular mils), nor MM to indicate millions, nor C to indicate hundreds, etc., because of conflicts with the SI prefixes.

3.5.5 Attachments to unit symbols

Attachment of letters to a unit symbol as a means of giving information about the nature of the quantity under consideration is incorrect. Thus, do not use MWe, Vac, VAC, kJt, “megawatts electrical (power),” “volts ac,” or “kilojoules thermal (energy).” If the context leaves any doubt as to what is meant, qualify the name of the quantity appropriately. For example, “... an electric power of 1.4 MW.”

For the same reason, do not attempt to construct SI equivalents of the abbreviations “psia” (pounds per square inch, absolute) and “psig,” which are often used to distinguish between absolute and gage pressure. Wherever possible use instead “…at a gage pressure of 13 kPa” or “...at an absolute pressure of 13 kPa.”

Some contexts do not allow the written-out style recommended above: table headings, gage dials, graph labels are examples. In such situations only, a modifier may be added (after a space) in parentheses. For example, “kPa (gage),” “kPa (absolute),” and “V (ac)” are then permitted.

Annex A

(informative)

Tables of conversion factors

A.1 General

The following tables provide factors to convert values expressed in various units into equivalent values expressed in units of the SI, including units accepted for use with the International System of Units. See Annex B for information on conversion and rounding.

In most cases, the converted values are expressed in terms of the base and derived units of SI to provide a coherent presentation of the conversion factors and to facilitate computations. If desired, the user can select appropriate SI prefixes (see 3.2.2) and shift the decimal marker. For example, the factor for the International Table British thermal unit leads to 1055.056 J when applied directly, and this is seen to be equal to 1.055 056 kJ.

A.2 Notation

In most cases, factors are given to seven significant digits. If fewer digits are shown, more are not warranted. Factors that are too large or too small to fit into the field of the tables are given in exponential notation. For example, the factor for converting an area in circular mils into square millimeters is given as 5.067 075 E–04, which is to be interpreted as $5.067\ 075 \times 10^{-4}$ or 0.000 506 707 5. The order of magnitude of each factor given in decimal notation in the tables that follow is obvious to the eye, as the decimal points of those multipliers are aligned.

A conversion factor that is set in **boldface** is exact.

A.3 Use

The table entries are to be interpreted as follows:

To convert from	To	Multiply by
foot	meter (m)	**0.304 8**
cubic inch	cubic meter (m^3)	1.638 706 E–05

means 1 foot = 0.304 8 meter (exactly)

1 cubic inch = $1.638\ 706 \times 10^{-5}$ cubic meter

To convert values expressed in SI units to values expressed in various other units, *divide* by the conversion factors.

The conversion factors for other compound units can be generated from factors shown in the tables, as follows:

Example:

To find the conversion factor required to convert pound foot per second (a unit of momentum) to kilogram meter per second, use

1 lb = 0.453 592 37 kg (exactly) and 1 ft = 0.3048 m (exactly)

By substitution, 1 lb · ft/s = (0.453 592 37 kg) · (0.3048 m/s) = 0.138 254 954 376 kg · m/s (exactly). Rounded to seven significant digits, the conversion factor is 0.138 255 0. Note that the seventh decimal place in this conversion factor (i.e., the last zero) is significant.

A.4 Tables

A.4.1 Organization

In Table A.1, all units are listed in alphabetical order. In Table A.2 to Table A.7, the factors are classified according to the following categories:

A.2 Space and time

A.3 Mechanics

A.4 Heat

A.5 Electricity and magnetism

A.6 Radiology

A.7 Light

Table A.1—Alphabetical list of units

To convert from	To	Multiply by[a]	NOTE
abampere	ampere (A)	**10**	
abcoulomb	coulomb (C)	**10**	
abfarad	farad (F)	**1.0 E+09**	
abhenry	henry (H)	**1.0 E–09**	
abmho	siemens (S)	**1.0 E+09**	
abohm	ohm (W)	**1.0 E–09**	
abvolt	volt (V)	**1.0 E–08**	
acre (43 560 square U.S. survey feet)	square meter (m^2) hectare (ha)	4046.873 0.404 687 3	[1]

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
acre-foot	cubic meter (m^3)	1233.489	
ampere hour	coulomb (C)	**3600**	
ampere turn	ampere (A)	**1.0**	
ampere turn per inch	ampere per meter (A/m)	**39.370 1**	
ampere turn per meter	ampere per meter (A/m)	**1.0**	
ångström (Å)	meter (m) nanometer (nm)	**1.0 E–10** **0.1**	
are (a)	square meter (m^2)	**100**	
astronomical unit (ua)	meter (m)	1.495 979 E+11	
atmosphere, standard (atm)	pascal (Pa) kilopascal (kPa)	**1.013 25 E+05** **01.325**	[2]
atmosphere, technical (1 kgf/cm^2) (at)	pascal (Pa) kilopascal (kPa)	**9.806 65 E+04** **98.066 5**	[2]
bar (bar)	pascal (Pa) kilopascal (kPa)	**1.0 E+05** **100**	
barn (b)	square meter (m^2)	**1.0 E–28**	
barn (b)	square meter (m^2)	**1.0 E–28**	
barrel (oil, 42 U.S. gallons)	cubic meter (m^3) liter (L)	0.158 987 3 158.987 3	
becquerel (Bq)	one per second	**1.0**	
biot (see also abampere)	ampere (A)	**1.0**	
board foot			[9]
British thermal unit (Btu) (International Table)	joule (J)	1055.056	[3]
British thermal unit (Btu) (thermochemical)	joule (J)	1054.350	[3]
Btu foot per hour square foot degree Fahrenheit [$Btu \cdot ft/(h \cdot ft^2 \cdot °F)$]	watt per meter kelvin [$W/(m \cdot K)$]	1.730 735	[3]
Btu inch per hour square foot degree Fahrenheit [$Btu \cdot in/(h \cdot ft^2 \cdot °F)$]	watt per meter kelvin [$W/(m \cdot K)$]	0.144 227 9	[3]
Btu per cubic foot (Btu/ft^3)	joule per cubic meter (J/m^3)	3.725 895 E+04	[3]
Btu per degree Fahrenheit (Btu/°F)	joule per kelvin (J/K)	1899.101	[3]

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
Btu per degree Rankine (Btu/°R)	joule per kelvin (J/K)	1899.101	[3]
Btu per hour (Btu/h)	watt (W)	0.293 071 1	[3]
Btu per hour square foot [Btu/(h · ft^2)]	watt per square meter (W/m^2)	3.154 591	[3]
Btu per hour square foot degree Fahrenheit [Btu/(h · ft^2 · °F)]	watt per square meter kelvin	5.678 263	[3]
Btu per pound	joule per kilogram (J/kg)	**2326**	[3]
Btu per pound degree Fahrenheit [Btu/(lb · °F)]	joule per kilogram kelvin [J/(kg · K)]	**4186.8**	[3]
Btu per pound-mole	joule per kilomole (J/kmol)	**2326**	[3]
Btu per pound-mole degree Fahrenheit	joule per kilomole kelvin [J/(kmol · K)]	**4186.8**	[3]
Btu per second (Btu/s)	watt (W)	1055.056	[3]
Btu per square foot (Btu/ft^2)	joule per square meter (J/m^2)	1.135 653 E+04	[3]
bushel (U.S.) (bu)	cubic meter (m^3)	0.035 239 07	[6]
calorie (thermochemical) (cal)	joule (J)	**4.184**	[3]
Calorie, nutrition (kilocalorie) (Cal, kcal)	joule (J)	**4184**	[3]
calorie per centimeter second degree Celsius [cal/(cm · s · °C)]	watt per meter kelvin [W/(m · K)]	**418.4**	[3]
calorie per gram (cal/g)	joule per kilogram (J/kg)	**4184**	[3]
calorie per gram degree Celsius [cal/(g · °C)]	joule per kilogram kelvin [J/(kg · K)]	**4184**	[3]
calorie per mole (cal/mol)	joule per mole (J/mol)	**4.184**	[3]
calorie per mole degree Celsius [cal/(mol · °C)]	joule per mole kelvin [(J/(mol · K)]	**4.184**	[3]
calorie per second (cal/s)	watt (W)	**4.184**	[3]
calorie per square centimeter (cal/cm^2)	joule per square meter (J/m^2)	**4.184 E+04**	[3]
calorie per square centimeter minute [cal/(cm^2 · min)]	watt per square meter (W/m^2)	697.333 3	[3]
calorie per square centimeter second [cal/(cm^2 · s)]	watt per square meter (W/m^2)	**4.184 E+04**	[3]
candela per square inch (cd/in^2)	candela per square meter (cd/m^2)	1550.003	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
candle, candlepower (cd)	candela (cd)	**1.0**	
carat (metric)	kilogram (kg) gram (g)	**0.000 2** **0.2**	
centimeter of water (cmH$_2$O)	pascal (Pa)	**98.066 5**	[2]
centipoise (cP)	pascal second (Pa · s)	**0.001**	
centistokes (cSt)	square meter per second (m^2/s)	**1.0 E–06**	
chain (66 U.S. survey feet) (ch)	meter (m)	20.116 84	[1]
circular mil (cmil)	square millimeter (mm^2)	5.067075E–04	
clo	kelvin square meter per watt (K · m^2/W)	0.155	
cord	cubic meter (m^3)	3.625	
cubic foot (ft^3)	cubic meter (m^3)	0.028 316 85	
cubic foot per minute (cfm)	cubic meter per second (m^3/s) liter per second (L/s)	4.719 474 E–04 0.471 947 4	
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)	0.028 316 85	
cubic inch (in^3)	cubic meter (m^3)	**1.638 706 4 E–05**	
cubic inch per minute (in^3/min)	cubic meter per second (m^3/s)	2.731 177 E–07	
cubic mile (mi^3)	cubic meter (m^3) cubic kilometer (km^3)	4.168 182 E+09 4.168 182	
cubic yard (yd^3)	cubic meter (m^3)	0.764 554 9	
cubic yard per minute (yd^3/min)	cubic meter per second (m^3/s)	0.012 742 58	
cup (U.S.)	cubic meter (m^3) liter (L) milliliter (mL)	2.366 E–04 0.236 6 236.6	
curie (Ci)	becquerel (Bq)	**3.7 E+10**	
dalton	kilogram (kg)	1.660 540 E–27	
darcy	square meter (m^2)	9.869 233 E–13	[7]
day (24 h) (d)	second (s)	**8.64 E+04**	
day (sidereal)	second (s)	8.616 409 E+04	
debye (D)	coulomb meter (C · m)	3.335 641 E–30	
degree	radian (rad)	**π /180 =** 0.017 453 29	

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[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
degree Celsius (°C) (interval)	kelvin (K)	**1.0**	
degree Celsius (°C) (temperature)	kelvin (K)	$T_{\mathrm{K}} = t_{^\circ\mathrm{C}} + \mathbf{273.15}$	
degree centigrade (interval)	degree Celsius (°C)	**1.0**	
degree centigrade (temperature)	degree Celsius (°C)	$t_{^\circ\mathrm{C}} \approx t_{\mathrm{centigrade}}$	
degree Fahrenheit (°F) (interval)	kelvin (K) degree Celsius (°C)	0.555 555 6 0.555 555 6	
degree Fahrenheit (°F) (temperature)	kelvin (K) degree Celsius (°C)	$T_{\mathrm{K}} = (t_{^\circ\mathrm{F}} + \mathbf{459.67})/\mathbf{1.8}$ $t_{^\circ\mathrm{C}} = (t_{^\circ\mathrm{F}} - \mathbf{32})/\mathbf{1.8}$	
degree Fahrenheit hour per Btu (°F · h/Btu)	kelvin per watt (K/W)	1.895 634	
degree Fahrenheit square foot hour per Btu (°F · ft^2 · h/Btu)	kelvin square meter per watt (K · m^2/W)	0.176 110 2	
degree Fahrenheit square foot hour per Btu inch [°F · ft^2 · h/(Btu · in)]	kelvin meter per watt (K · m/W)	6.933 472	
degree Rankine (°R) (interval)	kelvin (K)	0.555 555 6	
degree Rankine (°R) (temperature)	kelvin (K)	$T_{\mathrm{K}} = T_{^\circ\mathrm{R}}/\mathbf{1.8}$	
denier	kilogram per meter (kg/m)	1.111 111 E–07	
dyne (dyn)	newton (N)	**1.0 E–05**	
dyne centimeter (dyn · cm)	newton meter (N · m)	**1.0 E–07**	
dyne per square centimeter (dyn · cm2)	pascal (Pa)	**0.1**	
electronvolt (eV)	joule (J)	1.602 176 E–19	[10]
erg (erg)	joule (J)	**1.0 E–07**	
erg per second (erg/s)	watt (W)	**1.0 E–07**	
erg per square centimeter (erg/cm^2)	joule per square meter (W/m^2)	**0.001**	
faraday (based on carbon 12)	coulomb (C)	9.648 531 E+04	
fathom	meter (m)	1.828 8	
fermi	meter (m) femtometer (fm)	**1.0 E–15** 1.0	
foot (ft)	meter (m)	**0.304 8**	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
foot, U.S. survey	meter (m)	0.304 800 6	[1]
foot of water (ftH_2O)	pascal (Pa) kilopascal (kPa)	2989.07 2.989 07	[2]
foot per hour (ft/h)	meter per second (m/s)	8.466 667 E–05	
foot per minute (ft/min)	meter per second (m/s)	**0.005 08**	
foot per second (ft/s)	meter per second (m/s)	**0.304 8**	
foot per second squared (ft/s^2)	meter per second squared (m/s^2)	**0.304 8**	
foot pound-force (ft · lbf) (torque)	newton meter (N · m)	1.355 818	
foot pound-force (ft · lbf) (energy)	joule (J)	1.355 818	
foot pound-force per cubic foot ($ft \cdot lbf/ft^3$)	joule per cubic meter (J/m^3)	47.880 25	
foot pound-force per hour (ft · lbf /h)	watt (W)	3.766 161 E–04	
foot pound-force per minute (ft · lbf /min)	watt (W)	0.022 596 97	
foot pound-force per second (ft · lbf /s)	watt (W)	1.355 818	
foot pound-force per square foot ($ft \cdot lbf/ft^2$)	joule per square meter (J/m^2)	14.593 902	
foot pound-force per square foot second [$ft \cdot lbf/(ft^2 \cdot s)$]	watt per square meter (W/m^2)	14.593 902	
foot poundal (ft · pdl)	joule (J)	0.042 140 11	
footcandle (fc)	lux (lx)	10.763 91	
footlambert (fL)	candela per square meter (cd/m^2)	3.426 259	
franklin (Fr)	coulomb (C)	3.335 641 E–10	
g_n (standard acceleration due to gravity)	meter per second squared (m/s^2)	**9.806 65**	
gal (Gal) (cm/s^2)	meter per second squared (m/s^2)	0.01	
gallon (Imperial) (gal)	cubic meter (m^3) liter (L)	4.54609 E–03 4.546 0	
gallon (U.S.) (231 in^3) (gal)	cubic meter (m^3) liter (L)	3.785 412 E–03 3.785 412	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
gallon (U.S.) per day (gal/d)	cubic meter per second (m^3/s) liter per second (L/s)	4.381 264 E–08 4.381 264 E–05	
gallon (U.S.) per minute (gpm)	cubic meter per second (m^3/s) liter per second (L/s)	6.309 020 E–05 0.063 090 20	
gallon (U.S.) per horsepower hour	cubic meter per joule (m^3/J)	1.410 089 E–09	
gamma (γ)	tesla (T)	**1.0 E–09**	
gauss (G)	tesla (T)	**1.0 E–04**	
gilbert (Gi)	ampere (A)	**$10/4\pi$** = 0.795 774 7	
grad, grade, gon (gon)	radian (rad) degree of angle (°)	**$2\pi/400$ = 0.015 707 96** **0.9**	
grain (gr)	kilogram (kg) milligram (mg)	**6.479 891 E–05** **64.798 91**	
grain per gallon (U.S.) (gr/gal)	kilogram per cubic meter (kg/m^3) milligram per liter (mg/L)	0.017 118 06 17.118 06	
gravity, standard acceleration due to (g_n)	meter per second squared (m/s^2)	**9.806 65**	
hectare (ha)	square meter (m^2)	**1.0 E+04**	
horsepower (550 ft · lbf/s) (hp)	watt (W)	745.699 9	
horsepower (boiler) (approximately 33 470 Btu/h)	watt (W)	9809.50	
horsepower (electric)	watt (W)	**746**	
horsepower (metric)	watt (W)	735.498 8	
hour (h)	second (s)	**3600**	
hour (sidereal)	second (s)	3590.170	
hundredweight, long (112 lb)	kilogram (kg)	50.802 35	
hundredweight, short (100 lb) (cwt)	kilogram (kg)	45.359 24	
inch (in)	meter (m)	**0.025 4**	
inch of mercury (inHg)	pascal (Pa)	3386.3	[2]
inch of water (inH$_2$O)	pascal (Pa)	249.089	[2]
inch ounce-force (torque)	newton meter (N · m)	7.061 552 E–03	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
inch pound-force (in · lbf)	newton meter (N · m)	0.112 984 8	
jansky (Jy)	watt per square meter hertz [W/(m^2 · Hz)]	**1.0 E–26**	
kilocalorie (thermochemical) (kcal)	joule (J)	**4184**	[3]
kilogram-force (kgf)	newton (N)	**9.806 65**	
kilogram-force meter (kgf · m)	newton meter (N · m)	**9.806 65**	
kilogram-force per square centimeter (kgf/cm^2)	kilopascal (kPa)	**98.066 5**	
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	**9.806 65**	
kiloliter (kL) (=m^3)	liter (L)	**1000**	
kilometer per hour (km/h; kph)	meter per second (m/s)	**1000/3600** = 0.277 777 8	
kilopond (kilogram-force) (kp)	newton (N)	**9.806 65**	
kilowatthour (kWh)	joule (J)	**3.6 E+06**	
kip (1000 lbf)	kilonewton (kN)	4.448 222	
kip per square inch (ksi)	megapascal (MPa)	6.894 757	
knot (nautical mile per hour) (kn)	meter per second (m/s)	0.514 444 4	
lambert (L)	candela per square meter (cd/m^2)	**(1/π) E+04 =** 3183.099	
langley (cal/cm^2)	joule per square meter (J/m^2)	**4.184 E+04**	
light year (l.y.)	meter (m)	9.460 528 E+15	
lumen per square foot	lumen per square meter (lm/m^2)	10.763 91	
maxwell (Mx)	weber (Wb)	**1.0 E–08**	
metric ton (t)	kilogram (kg)	**1000**	
mho	siemens (S)	**1.0**	
microinch (µin)	meter (m)	**2.54 E–08**	
microliter (mL) (= mm^3)	liter (L)	**1.0 E–06**	
micron (= micrometer, µm)	meter (m)	**1.0 E–06**	
mil (0.001 in) (mil)	meter (m) millimeter (mm)	**2.54 E–05** **0.025 4**	[8]

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
mil (angle)	radian (rad) degree (°)	**2 π /6400** = 9.817 477 E–04 0.056 25	
mile, international (5280 ft) (mi)	meter (m)	**1609.344**	
mile, nautical (nmi)	meter (m)	**1852**	
mile, U.S. statute	meter (m)	1609.347	[1]
mile per gallon (U.S.) (mpg)	kilometer per liter (km/L)	0.425 143 7	[5]
mile per hour (mi/h; mph)	meter per second (m/s) kilometer per hour (km/h)	**0.447 04** **1.609 344**	
mile per minute (mi/min)	meter per second (m/s)	**26.822 4**	
millibar (mbar)	pascal (Pa) hectopascal (hPa)	**100** **1**	
milliliter (mL) (= cm^3)	liter (L)	**0.001**	
millimeter of mercury (mmHg)	pascal (Pa)	133.322 4	[2]
minute (arc)	radian (rad)	2.908 882 E–04	
minute	second (s)	**60**	
minute (sidereal)	second (s)	59.836 17	
nautical mile (nmi)	meter (m)	**1852**	
oersted (Oe)	ampere per meter (A/m)	**1000/4π=** 79.577 47	
oersted centimeter (Oe · cm)	ampere (A)	0.795 774 7	
ohm centimeter (Ω · cm)	ohm meter (Ω · m)	**0.01**	
ohm circular-mil per foot (Ω · mil/ft)	ohm meter (Ω · m) ohm square millimeter per meter (Ω · mm^2/m)	1.662 426 E–09 0.001 662 426	
ounce (avoirdupois) (oz)	kilogram (kg) gram (g)	0.028 349 52 28.349 52	
ounce (Imperial fluid) (fl oz)	cubic meter (m^3)	2.841 306 E–05	
ounce (troy or apothecary) (oz)	kilogram (kg)	0.031 134 8	
ounce (U.S. fluid) (oz)	cubic meter (m^3) milliliter (mL)	2.957 353 E–05 29.573 53	
ounce-force (ozf)	newton (N)	0.278 013 9	
ounce-force inch (ozf · in) (torque)	newton meter (N · m)	7.061 552 E–03	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
ounce (av) per cubic inch (oz/in^3)	kilogram per cubic meter (kg/m^3)	1729.994	
ounce (av) per gallon (U.S.) (oz/gal)	kilogram per cubic meter (kg/m^3)	7.489 152	
ounce per square foot (oz/ft^2)	kilogram per square meter (kg/m^2)	0.305 151 7	
ounce per square yard (oz/yd^2)	kilogram per square meter (kg/m^2)	0.033 905 75	
parsec (pc)	meter (m)	3.085678 E+16	
peck (U.S.) (pk)	cubic meter (m^3) liter (L)	8.809 768 E–03 8.809 768	
pennyweight (dwt)	kilogram (kg)	1.555 174 E–03	
perm (0 °C)	kilogram per pascal second square meter [kg/(Pa · s · m^2)]	5.721 35 E–11	
perm (23 °C)	kilogram per pascal second square meter [kg/(Pa · s · m^2)]	5.745 25 E–11	
perm inch (0 °C)	kilogram per pascal second meter [kg/(Pa · s · m)]	1.453 22 E–12	
perm inch (23 °C)	kilogram per pascal second meter [kg/(Pa · s · m)]	1.459 29 E–12	
phot (ph)	lumen per square meter (lm/m^2)	**1.0 E+04**	
pica (computer) (1/6 in) (pi)	meter (m) millimeter (mm)	0.004 233 333 4.233 333	
pica (printer's) (pi)	meter (m) millimeter (mm)	0.004 217 5 4.217 5	
pint (Imperial) (pt)	cubic meter (m^3) liter (L)	**5.682 612 5 E–04** **0.568 261 25**	
pint (U.S. dry) (dry pt)	cubic meter (m^3) liter (L)	5.506 1 E–04 0.550 61	
pint (U.S. liquid) (pt)	cubic meter (m^3) liter (L)	4.731 76 E–04 0.473 176	
point (computer) (1/72 in) (p)	meter (m)	3.527 778 E–04	
point (printer's) (p)	meter (m) millimeter (mm)	3.514 6 E–04 0.351 46	
poise (p)	pascal second (Pa · s)	**0.1**	
pound (avoirdupois) (lb)	kilogram (kg)	**0.453 592 37**	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
pound (troy or apothecary) (lb)	kilogram (kg)	0.373 241 7	
poundal (pdl)	newton (N)	0.138 255 0	
poundal per square foot (pdl/ft^2)	pascal (Pa)	1.488 164	
pound-force (lbf)	newton (N)	4.448 222	
pound-force foot (lbf · ft) (torque)	newton meter (N · m)	1.355 818	
pound-force inch (lbf · in) (torque)	newton meter (N · m)	0.112 984 8	
pound-force per foot (lbf/ft)	newton per meter (N/m)	14.593 90	
pound-force per inch (lbf/in)	newton per meter (N/m)	175.126 8	
pound-force per pound (lbf/lb)	newton per kilogram (N/kg)	**9.806 65**	
pound-force per square foot (lbf/ft^2) (psf)	pascal (Pa)	47.880 26	
pound-force per square inch (lbf/in^2) (psi)	pascal (Pa) kilopascal (kPa)	6894.757 6.894 757	
pound-force second per square foot (lbf · s/ft$^{2)}$	pascal second (Pa · s)	47.880 26	
pound-force second per square inch (lbf · s/in^2)	pascal second (Pa · s)	6894.757	
pound-mole	mole	**453.592 37**	
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)	16.018 46	
pound per cubic inch (lb/in^3)	kilogram per cubic meter (kg/m^3)	2.767 990 E+04	
pound per cubic yard (lb/yd^3)	kilogram per cubic meter (kg/m^3)	0.593 276 4	
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164	
pound per foot hour [lb/(ft · h)]	pascal second (Pa · s)	4.133 789 E–04	
pound per gallon (U.S.) (lb/gal)	kilogram per cubic meter (kg/m^3) kilogram per liter (kg/L)	119.826 4 0.119 826 4	
pound per hour (lb/h)	kilogram per second (kg/s)	1.259 979 E–04	
pound per inch (lb/in)	kilogram per meter (kg/m)	17.857 97	
pound per minute (lb/min)	kilogram per second (kg/s)	0.007 559 873	
pound per pound-mol	kilogram per mole (kg/mol)	**0.001**	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428	
pound per horsepower hour [lb/(hp · h)]	kilogram per joule (kg/J)	1.689 659 E–07	
pound per yard (lb/yd)	kilogram per meter (kg/m)	0.496 054 6	
quad (= 10^{15} Btu)	joule (J)	1.055 E+18	
quart (U.S. dry) (dry qt)	cubic meter (m^3) liter (L)	0.001 101 221 1.101 221	
quart (U.S. liquid) (qt)	cubic meter (m^3) liter (L)	9.463 529 E–04 0.946 352 9	
rad (absorbed dose) (rad)	gray (Gy)	**0.01**	
rem (dose equivalent) (rem)	sievert (Sv)	**0.01**	
revolution (r)	radian (rad)	**2π** = 6.283 185	
revolution per minute (rpm)	radian per second (rad/s)	**2π/60** = 0.104 719 8	
rhe	1 per pascal second [1/(Pa · s)]	**10**	
rod (16.5 U.S. survey feet) (rd)	meter (m)	5.029 210	[1]
roentgen (R)	coulomb per kilogram (C/kg)	**2.58 E–04**	
second (angle)	radian (rad)	4.848 137 E–06	
second (sidereal)	second (s)	0.997 269 6	
shake	second (s) nanosecond (ns)	**1.0 E–08** **10**	
slug (slug)	kilogram (kg)	14.593 90	
slug per cubic foot (slug/ft^3)	kilogram per cubic meter (kg/m^3)	5.153 788 E+02	
slug per foot (slug/ft)	kilogram per meter (kg/m)	4.788026 E+01	
slug per foot second (slug/ft · s)	pascal second (Pa · s)	4.788 026 E+01	
slug per square foot (slug/ft^2)	kilogram per square meter (kg/m^2)	1.570 875 E+02	
square foot (ft^2)	square meter (m^2)	**0.092 903 04**	
square foot per hour (ft^2/h)	square meter per second (m^2/s)	**2.580 64 E–05**	
square inch (in^2)	square meter (m^2)	**6.451 6 E–04**	
square mile (mi^2)	square meter (m^2)	2.589 988 E+06	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
square yard (yd^2)	square meter (m^2)	0.836 127 4	
standard acceleration due to gravity (g_n)	meter per second squared (m/s^2)	**9.806 65**	
statampere	ampere (A)	3.335 641 E–10	
statcoulomb	coulomb (C)	3.335 641 E–10	
statfarad	farad (F)	1.112 650 E–12	
stathenry	henry (H)	8.987 552 E+11	
statmho	siemens (S)	1.112 650 E–12	
statohm	ohm (Ω)	8.987 552 E+11	
statvolt	volt (V)	299.792 5	
stere (st)	cubic meter (m^3)	**1.0**	
stilb (sb)	candela per square meter (cd/m^2)	**1.0 E+04**	
stokes (St)	square meter per second (m^2/s)	**1.0 E–04**	
tablespoon (tbs)	cubic meter (m^3) milliliter (mL)	1.479 E–05 14.79	
teaspoon (tsp)	cubic meter (m^3) milliliter (mL)	4.929 E–06 4.929	
tex	kilogram per meter (kg/m)	**1.0 E–06**	
therm (EEC) (therm)	joule (J)	**1.055 06 E+08**	[4]
therm (U.S.) (therm)	joule (J)	**1.054 804 E+08**	[4]
ton, assay (AT)	gram (g)	29.166 67	
ton, long (2240 lb) (ton)	kilogram (kg)	1016.047	
ton, register	cubic meter (m^3)	2.831 685	
ton, short (2000 lb) (ton)	kilogram (kg)	907.184 7	
ton (from energy equivalent of one ton of TNT) (106 kcal)	joule (J)	**4.184 E+09**	
ton of oil equivalent (10^7 kcal)	joule (J)	**4.184 E+10**	
ton of refrigeration (12 000 Btu/h)	watt (W)	3516.853	[3]
ton (long) per cubic yard	kilogram per cubic meter (kg/m^3)	1328.939	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

Table A.1—Alphabetical list of units (continued)

To convert from	To	Multiply by[a]	NOTE
ton (short) per cubic yard	kilogram per cubic meter (kg/m^3)	1186.553	
ton (short) per hour (ton/h)	kilogram per second (kg/s)	0.251 995 8	
torr (Torr)	pascal (Pa)	133.322	
unified atomic mass unit (u)	kilogram (kg)	1.660 538 73 E–27	[10]
unit pole	weber (Wb)	1.256 637 E–07	
watthour (W · h)	joule (J)	**3600**	
watt per square centimeter (W/cm^2)	watt per square meter (W/m^2)	**1.0 E+04**	
watt per square inch (W/in^2)	watt per square meter (W/m^2)	1550.003	
watt second (W · s)	joule (J)	1.0	
weber per square meter (Wb/m^2)	tesla (T)	**1.0**	
yard (yd)	meter (m)	**0.914 4**	
year of 365 days (y)	second (s)	**3.153 6 E+07**	
year (sidereal)	second (s)	3.155 815 E+07	
year (tropical)	second (s)	3.155 693 E+07	

[a] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.

NOTES

[1] The U.S. Metric Law of 1866 gave the relationship 1 meter equals 39.37 inches. Since 1893, the U.S. yard has been derived from the meter. In 1959, a refinement was made in the definition of the yard to bring the U.S. yard and the yard used in other countries into agreement. The U.S. yard was changed from 3600/3937 meter to 0.9144 meter exactly. The new length is shorter by two parts in a million.

Also in 1959, it was decided that any data in feet derived from and published as a result of geodetic surveys within the U.S. would remain with the old standard (1 foot = 1200/3937 meter). This foot is named the U.S. survey foot. Lengths, areas, and volumes based on the U.S. survey foot are identified in the conversion tables by reference to this note. Those not so identified are based on the yard equal to 0.9144 meter exactly.

[2] The actual pressure corresponding to the height of a vertical column of fluid depends on the local gravitational field and the density of the fluid, which in turn depends upon the temperature. The conversion factors given here are conventional values adopted by ISO. They assume a standard gravitational field ($g_n = 9.806\ 65$ N/kg), a density of water equal to 1000 kg/m^3, and a density of mercury of 13 595.1 kg/m^3.

[3] The British thermal unit used in these tables is the International Table Btu. The Fifth International Conference on the Properties of Steam (London, July 1956) defined the calorie (International Table) as 4.1868 J. Therefore, the exact conversion factor for the Btu (International Table) is 1.055 055 852 62 kJ. Conversion factors for the other forms of the Btu include the following:

British thermal unit (mean)	1055.87 J
British thermal unit (thermochemical)	1054.350 J
British thermal unit (39 °F)	1059.67 J
British thermal unit (59 °F)	1054.80 J
British thermal unit (60 °F)	1054.68 J

The calorie used in these tables is the thermochemical calorie, defined as 4.184 J exactly, which has been widely used in scientific work. Other forms of the calorie that have seen practical application include the following:

calorie (International Table)	4.186 8 J (by definition)
calorie (mean)	4.190 02 J
calorie (15 °C)	4.185 80 J
calorie (20 °C)	4.181 90 J

The International Table calorie has been frequently used in European engineering work. Various kilocalories have often been used, sometimes being called “kilogram-calories.” The so-called “calorie” (or Calorie) used in the field of nutrition is in fact a kilocalorie (4.184 kJ).

[4] The therm (EEC) was legally defined in the Council Directive of 20 December 1979, Council of the European Economic Communities, now the European Union. The therm (U.S.) is legally defined in the Federal Register of 27 July 1968. Although the therm (EEC), which is based on the International Table Btu, is frequently used by engineers in the U.S., the therm (U.S.) is the legal unit used by the natural gas industry in the U.S.

[5] In some countries automotive fuel efficiency is expressed in terms of fuel consumption, stated in liters per hundred kilometers. Fuel consumption in liters per 100 kilometers is equal to 235.215 divided by the fuel economy expressed in miles per U.S. gallon.

[6] Agricultural products are often sold by the bushel in the U.S. The mass per unit volume of such products varies considerably owing to differences in variety, size, or condition of the commodity, tightness of pack, degree to which the container is heaped, etc. The following conversion factors for 1 bushel are used by the U.S. Department of Agriculture for statistical purposes:

barley	21.8 kg
corn, shelled	25.4 kg
oats	14.5 kg
potatoes	27.2 kg
soybeans	27.2 kg
wheat	27.2 kg

[7] The darcy is a unit for measuring permeability of porous solids. The darcy is not a unit of area.

[8] The abbreviation mil is sometimes used erroneously to mean millimeter or milliliter.

[9] No conversion factor is given for board foot because the board foot is not a well-defined unit of volume. Calculation of the number of board feet in a piece of lumber is based on the nominal dimensions of the cross section.

[10] See Table 7.

Table A.2—Classified list of units—space and time

Conversion factors to SI units are given in Table A.1

ANGLE

SI Unit:
radian

Units in use with SI:
degree
minute
second
revolution

Other units:
grad, grade, gon
mil

LENGTH

SI Unit:
meter

Other units:
ångström
astronomical unit
chain
fathom
fermi
foot
inch
light year
microinch
micron
mil
mile (international or U.S. statute)
mile, nautical
parsec
pica
point
rod
yard

AREA

SI Unit:
square meter

Unit in use with SI:
hectare

Other units:
acre
are
barn
circular mil
square foot
square inch
square mile
square yard

VOLUME (includes CAPACITY)

SI Unit:
cubic meter

Unit in use with SI:
liter

Other units:
acre-foot
barrel
board foot
bushel
cord
cubic foot
cubic inch
cubic mile
cubic yard
cup
gallon (Imperial or U.S.)
ounce (Imperial or U.S.)
peck
pint (Imperial, U.S. dry, or U.S. liquid)
quart (U.S. dry or U.S. liquid)
stere
tablespoon
teaspoon
ton (register)

TIME

SI Unit:
second

Units in use with SI
day (mean solar)
hour
minute
second
sidereal day
sidereal hour
sidereal minute

Other units:
shake
year (365-day, sidereal, or tropical)

VELOCITY (includes SPEED)

SI Unit:
meter per second

Other units:
foot per hour
foot per minute
foot per second
kilometer per hour
knot
mile per hour
mile per minute

ANGULAR VELOCITY

SI Unit:
radian per second

Units in use with SI
revolution per minute
revolution per second

ACCELERATION

SI Unit:
meter per second squared

Other units:
foot per second squared
g_n (standard acceleration due to gravity)
gal

VOLUME PER UNIT TIME (includes FLOW)

SI Unit:
cubic meter per second

Other units:
cubic foot per minute
cubic foot per second
cubic inch per minute
cubic yard per minute
gallon per day
gallon per minute

Table A.3—Classified list of units—mechanics

Conversion factors to SI units are given in Table A.1

MASS

SI Unit:
kilogram

Units in use with SI:
metric ton or tonne
unified atomic mass unit

Other units:
carat
dalton
grain
hundredweight (long or short)
ounce (avoirdupois or troy)
pennyweight
pound (avoirdupois or troy)
slug
ton (assay, long, metric, or short)

MASS PER UNIT TIME (includes FLOW)

SI Unit:
kilogram per second

Other units:
pound per hour
pound per minute
slug per second
ton per hour

MASS PER UNIT LENGTH

SI Unit:
kilogram per meter

Other units:
denier
pound per foot
pound per inch
slug per foot
tex

MASS PER UNIT AREA

SI Unit:
kilogram per square meter

Other units:
ounce per square foot
ounce per square yard
pound per square foot
slug per square foot

MASS PER UNIT VOLUME (includes DENSITY and MASS CONCENTRATION)

SI Unit:
kilogram per cubic meter

Other units:
grain per gallon
ounce per cubic inch
ounce per gallon
pound per cubic foot
pound per cubic inch
pound per cubic yard
pound per gallon
slug per cubic foot
ton (long or short) per cubic yard

FORCE

SI Unit:
newton

Other units:
dyne
kilogram-force
kilopond (same as kilogram-force)
kip (1000 pound-force)
ounce-force
poundal
pound-force

FORCE PER UNIT LENGTH

SI Unit:
newton per meter

Other units:
pound-force per foot
pound-force per inch

THRUST TO MASS RATIO

SI Unit:
newton per kilogram

Other unit:
pound-force per pound

BENDING MOMENT or TORQUE

SI Unit:
newton meter

Other units:
dyne centimeter
kilogram-force meter
ounce-force inch
pound-force foot
pound-force inch

PRESSURE or STRESS (force per unit area)

SI Unit:
pascal

Other units:
atmosphere (standard)
atmosphere (technical)
bar
centimeter of water
dyne per square centimeter
foot of water
inch of mercury
inch of water
kilogram-force per square centimeter
kilogram-force per square meter
kip per square inch
millibar
millimeter of mercury
poundal per square foot
pound-force per square foot
pound-force per square inch
torr

Table A.3—Classified list of units—mechanics (continued)

Conversion factors to SI units are given in Table A.1

DYNAMIC VISCOSITY

SI Unit:
pascal second

Other units:
centipoise
poise
pound-force second per square foot
pound-force second per square inch
pound per foot hour
pound per foot second
slug per foot second

KINEMATIC VISCOSITY

SI Unit:
square meter per second

Other units:
centistokes
square foot per hour
square foot per second
stokes

ENERGY and WORK

SI Unit:
joule (also called the watt second)

Unit in use with SI:
electronvolt

Other units:
British thermal unit (International Table or thermochemical)
calorie (thermochemical or nutritional)
erg
foot poundal
foot pound-force
kilocalorie
kilowatthour
quad
therm (EEC or U.S.)
ton (energy equivalent of one ton of TNT)
ton of oil equivalent
watthour

POWER

SI Unit:
watt

Other units:
erg per second
foot pound-force per hour
foot pound-force per minute
foot pound-force per second
horsepower (550 foot pound-force per second)
horsepower (boiler, electric, metric, or water)

POWER PER UNIT AREA

SI Unit:
watt per square meter

Other units:
erg per square centimeter second
foot pound-force per square foot second
watt per square centimeter
watt per square inch

Table A.4—Classified list of units—heat

Conversion factors to SI units are given in Table A.1

TEMPERATURE (AND TEMPERATURE INTERVAL)

SI Unit:
kelvin
degree Celsius (see 3.4.2)

Other units:
degree centigrade
degree Fahrenheit
degree Rankine

THERMAL ENERGY

SI Unit:
joule

Other units:
British thermal unit
calorie (thermochemical or nutritional)
kilocalorie
therm (EEC or U.S.)

MOLAR ENERGY

SI Unit:
joule per mole

Other units:
Btu per pound-mole
calorie per mole

HEAT FLOW RATE

SI Unit:
watt

Other units:
Btu per hour
Btu per second
calorie per minute
calorie per second
ton of refrigeration (12 000 Btu/h)

HEAT FLOW RATE PER UNIT AREA

SI Unit:
watt per square meter

Other units:
Btu per hour square foot
Btu per second square foot
calorie per square centimeter minute
calorie per square centimeter second

THERMAL CONDUCTIVITY

SI Unit:
watt per meter kelvin

Other units:
Btu foot per hour square foot degree Fahrenheit
Btu inch per hour square foot degree Fahrenheit
Btu inch per second square foot degree Fahrenheit
calorie per centimeter second degree Celsius

COEFFICIENT OF HEAT TRANSFER

SI Unit:
watt per square meter kelvin

Other units:
Btu per hour square foot degree Fahrenheit
Btu per second square foot degree Fahrenheit

THERMAL INSULANCE

SI Unit:
kelvin square meter per watt

Other units:
clo
degree Fahrenheit hour square foot per Btu

THERMAL RESISTIVITY

SI Unit:
kelvin meter per watt

Other units:
degree Fahrenheit hour square foot per Btu inch

THERMAL RESISTANCE

SI Unit:
kelvin per watt

Other unit:
degree Fahrenheit hour per Btu

THERMAL DIFFUSIVITY

SI Unit:
square meter per second

Other unit:
square foot per hour

HEAT CAPACITY AND ENTROPY

SI Unit:
joule per kelvin

Other units:
Btu per degree Fahrenheit
Btu per degree Rankine

Table A.4—Classified list of units—heat (continued)

Conversion factors to SI units are given in Table A.1

SPECIFIC HEAT CAPACITY

SI Unit:
joule per kilogram kelvin

Other units:
Btu per pound degree Fahrenheit
Btu per pound degree Rankine
calorie per gram degree Celsius

MOLAR HEAT CAPACITY

SI Unit:
joule per mole kelvin

Other units:
Btu per pound-mole degree Fahrenheit
calorie per mole degree Celsius

ENERGY PER UNIT AREA

SI Unit:
joule per square meter

Other units:
Btu per square foot
calorie per square centimeter
foot pound-force per square foot

ENERGY DENSITY

SI Unit:
joule per cubic meter

Other unit:
Btu per cubic foot
foot pound-force per cubic foot

SPECIFIC ENERGY

SI Unit:
joule per kilogram

Other units:
Btu per pound
calorie per gram

Table A.5—Classified list of units—electricity and magnetism

Conversion factors to SI units are given in Table A.1

ELECTRIC CHARGE

SI Unit:
coulomb

Other units:
abcoulomb
ampere hour
faraday
franklin
statcoulomb

CURRENT

SI Unit:
ampere

Other units:
biot
abampere
statampere

MAGNETIC FLUX DENSITY

SI Unit:
tesla (also called the weber per square meter)

Other units:
gauss
gamma

MAGNETIC FIELD STRENGTH

SI Unit:
ampere per meter

Other units:
oersted
ampere-turn per inch
ampere-turn per meter

MAGNETIC FLUX

SI Unit:
weber

Other units:
maxwell
unit pole

MAGNETOMOTIVE FORCE

SI Unit:
ampere

Other units:
ampere turn
gilbert
oersted centimeter

RESISTANCE

SI Unit:
ohm

Other units:
abohm
statohm

CONDUCTANCE

SI Unit:
siemens

Other units:
abmho
mho
statmho

INDUCTANCE

SI Unit:
henry

Other units:
abhenry
stathenry

CAPACITANCE

SI Unit:
farad

Other units:
abfarad
statfarad

ELECTROMOTIVE FORCE

SI Unit:
volt

Other units:
abvolt
statvolt

ELECTRIC DIPOLE MOMENT

SI Unit:
coulomb meter

Other unit:
debye

Table A.6—Classified list of units—radiology

Conversion factors to SI units are given in Table A.1

DOSE EQUIVALENT

SI Unit:
sievert

Other unit:
rem

ACTIVITY

SI Unit:
becquerel

Other unit:
curie

EXPOSURE

SI Unit:
coulomb per kilogram

Other unit:
roentgen

ABSORBED DOSE

SI Unit:
gray

Other unit:
rad

Table A.7—Classified list of units—light

Conversion factors to SI units are given in Table A.1

LUMINANCE

SI Unit:
candela per square meter

Other units:
candela per square inch
lambert
footlambert
stilb

ILLUMINANCE

SI Unit:
lux (also called the lumen per square meter)

Other unit
footcandle
phot

LUMINOUS INTENSITY

SI Unit:
candela

Other units:
candle
candlepower

LUMINOUS FLUX

SI Unit:
lumen

Annex B

(informative)

Rules for conversion and rounding

B.1 Terminology

A clear understanding of the following terms will help ensure reliable conversion and rounding practices.

B.1.1 accuracy: The degree of conformity of a measured or calculated value to some reference value, which may be specified or unknown. This concept includes the systematic error of an operation, which is seldom negligible or known exactly. (*Compare:* **precision.**)

B.1.2. deviation: Departure from a specified dimension or design requirement, usually defining upper and lower limits. *See also:* **tolerance.**

B.1.3 digit: One of the ten numerals (0 to 9) in the decimal number system. A position in a number.

B.1.4 dimension: A geometric element in a design, such as length or angle, or the magnitude of such a quantity. (Note that this usage differs from that in 3.4.8.)

B.1.5 figure (numerical): An arithmetic value expressed by one or more digits.

B.1.6 inch-pound units: Units based upon the yard and the pound commonly used in the United States of America and defined by the National Institute of Standards and Technology. Note that units having the same names in other countries may differ in magnitude.

B.1.7 nominal value: A value used to designate a characteristic of a device or to give a guide to its intended use.

B.1.8 precision: The degree of mutual agreement between individual measurements, namely their repeatability and reproducibility. (*Compare:* **accuracy.**)

B.1.9 significant digit: Any digit in a number that is necessary to define a numerical value. (See B.3.)

B.1.10 tolerance: The amount by which the value of a quantity is allowed to vary; thus, the tolerance is the algebraic difference between the maximum and minimum limits.

B.2 Introduction to conversion

Annex A contains conversion factors that show exact values or seven-digit accuracy for implementing these rules except where the nature of the dimension makes this impractical.

Conversion of quantities should be handled with careful regard to the implied correspondence between the accuracy of the data and the number of digits. In all conversions, the number of significant digits retained should be such that accuracy is neither sacrificed nor exaggerated. (For guidance concerning significant digits, see B.3.) For example, a length of 125 ft converts exactly to 38.1 m. If, however, the 125-ft length had been obtained by rounding to the nearest 5 ft, the conversion is 38 m; and if it had been obtained by rounding to the nearest 25 ft, the conversion is 40 m. See B.6 for guidance on rounding values.

Proper conversion procedure is to multiply the specified numerical value by the conversion factor exactly as in Annex A and then round to the appropriate number of significant digits. For example, to convert 3 feet 2 9/16 inches to meters:

$$(3\ \text{ft} \times 0.3048\ \text{m/ft}) + (2.5625\ \text{in} \times 0.0254\ \text{m/in}) = 0.979\ 487\ 5\ \text{m, which rounds to } 0.979\ \text{m}.$$

Do not round either the conversion factor or the numerical value before performing the multiplication, as accuracy may be reduced. After the conversion, the SI value may be expressed by a multiple or submultiple unit of SI by the use of an appropriate prefix, for example, 979 mm.

B.3 Significant digits

When converting integral values of units, consider the implied or required precision of the integral value converted. For example, the value "4 m" may represent 4 m, 4.0 m, 4.00 m, 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 value.

Any digit that is necessary to define a numerical value of a quantity is said to be significant. When measured to the nearest 1 m, a distance may be recorded as 157 m; the numerical value 157 has three significant digits. If the measurement had been made to the nearest 0.1 m, the distance might have been 157.4 m; the numerical value 157.4 has four significant digits.

Zeros may be used either to indicate a numerical value, like any other digit, or to indicate the order of magnitude of a number. According to the 1990 census, the U.S. population was 248 709 873. Rounded to thousands, this becomes 248 710 000. The first six digits of this number, including the leftmost zero, are significant; each measures a value. The last three digits are zeros that merely indicate the order of magnitude of the number rounded to the nearest thousand. Note that in this case the rounded number is the same if rounding is carried out to the nearest ten thousand.

The identification of significant digits is only possible through knowledge of the circumstances. For example, the number 1000 may be the result of rounding from 965, in which case only one zero is significant, or it may be rounded from 999.7, in which case all three zeros are significant.

B.4 Operations on data

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 should be observed when such data are to be added, subtracted, multiplied, or divided.

NOTE—The rules in B.4.1 and B.4.2 are approximations that often provide the appropriate number of significant digits. In some cases, however, the number of digits determined by these rules is too small by one (or even two) digits. If it is critical to determine the best number of significant digits, a more detailed analysis is required.

B.4.1 Addition and subtraction

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

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

The total indicates a precision that is not valid, so the total is rounded to 477 000 000 as called for by the rule.

B.4.2 Multiplication and division

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

Multiplication: 113.2 × 1.43 = 161.876, rounded to 162

Division: 113.2/1.43 = 79.16, rounded to 79.2

Addition: 113.2 + 1.43 = 114.63, rounded to 114.6

Subtraction: 113.2 – 1.43 = 111.77, rounded to 111.8

The product and quotient above 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.

B.4.3 Integers

Numbers used in the previous illustrations have all been estimates or measurements. Numbers that are exact are treated as though they consist of an infinite number of additional significant digits. More simply stated, when a count (an integer) 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.

B.5 Accuracy and rounding

Reliable conversions are obtained by multiplying the numerical value by the appropriate conversion factor given in Annex A. However, this product will usually imply an accuracy not warranted by the original value. Proper conversion procedure includes rounding this converted value to the number of significant digits commensurate with its accuracy before conversion.

The practical aspect of measuring must be considered when using SI equivalents. If a scale having divisions of 1/16 in was suitable for making the original measurements, a metric scale having divisions of 1 mm is suitable for measuring in SI units. Similarly, a gage or caliper graduated in divisions of 0.02 mm is comparable to one graduated in divisions of 0.001 in. Analogous situations exist in the measurement of mass, force, and other quantities.

B.5.1 General conversion

This method depends on first establishing the intended precision or accuracy of the quantity as a necessary guide to the number of digits to retain. This precision should relate to the number of digits in the original, but in many cases this is not a reliable indicator. The number 1.1875 may be the accurate decimalization of 1 3/16, which could have been expressed as 1.19. On the other hand, the number 2 may mean "about 2," or it may mean a very accurate value of 2, which should have been written 2.000.

Therefore, the intended precision of a value must be determined before converting. This estimate of intended precision should never be smaller than the accuracy of measurement, but it should usually be smaller than one-tenth the tolerance, if one exists. After estimating the precision, the converted value should be rounded to a minimum number of significant digits (see B.3) such that a unit of the last place is equal to or smaller than the converted precision.

Examples:

(1) A stirring rod is 6 in long. If the precision of the length of the rod is estimated to be about 1/2 in (± 1/4 in), the precision is 12.7 mm. The converted value of 152.4 mm should be rounded to the nearest 10 mm, which results in a length of 150 mm.

(2) The test pressure is 200 $\mathrm{lbf/in^2}$ (psi) ± 15 $\mathrm{lbf/in^2}$ (psi). Since one-tenth of the tolerance is 3 $\mathrm{lbf/in^2}$ (20.68 kPa), the converted value should be rounded to the nearest 10 kPa. Thus, 1378.9514 kPa ± 103.421 35 kPa becomes 1380 kPa ± 100 kPa.

B.5.2 Special cases

Round converted values to the minimum number of significant digits that will maintain the required accuracy, as discussed in Section B.3. In certain cases, deviation from this practice to make use of convenient or whole numbers may be feasible, in which case use the word "approximate" following the conversion. For example:

1 7/8 in = 47.625 mm exactly

= 47.6 mm normal rounding

= 47.5 mm (approximate) rounded to preferred number

= 48 mm (approximate) rounded to whole number

State limits, such as "not more than" or "maximum," so that the stated limit is not violated. For example, a specimen "at least 3 in wide" requires a width of at least 76.2 mm, or if rounded to two significant digits, 77 mm.

B.5.3 Conversion and tolerances

For information on conversion of linear dimensions of interchangeable parts, see ISO 370: 1975 [B23] and ASME B4.3-78 [B2].

B.5.4 Temperature

Normally, convert temperatures expressed in a whole number of degrees Fahrenheit or degrees Rankine to the nearest 0.5 K (or degree Celsius). As with other quantities, the number of significant digits to retain will depend upon the implied accuracy of the original value.

B.6 Rounding values

When rounding to fewer digits than the total number available, proceed as follows:

a) If the first digit discarded is less than 5, do not change the last digit retained. For example, 3.463 25, if rounded to four digits, would be 3.463; if rounded to three digits, 3.46.

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

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

Annex C

(informative)

Comments concerning the application of the International System of Units (SI)

C.1 Advantages of SI

SI is a rationalized selection of units from the metric systems developed before 1960, which individually are not new. SI is a coherent system with seven base units for which names, symbols, and precise definitions have been established.

C.1.1 Unique unit for every physical quantity

A great advantage of SI is that there is one and only one coherent SI unit for each physical quantity. From the seven SI base units, units for all other physical quantities are derived. SI derived units are defined using quantity equations such as $F = ma$ for force, $W = Fl$ for work, and $P = W/t$ for power. Some derived units have only their composite names, such as meter per second for velocity. Others have special names such as newton (N), joule (J), and watt (W) given to the SI units of force, energy, and power, respectively (see Table 3). The same units are used regardless of whether the underlying physical process is mechanical, electrical, chemical, thermal, or nuclear. Thus, the power of an internal combustion engine is expressed in watts, as are the rate of heat energy transfer of an air conditioner and the electrical power consumed by a light bulb.

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

C.1.2 Decimal relationships among SI units

Another advantage of SI is the decimal relation between multiples and submultiples of the unit for each physical quantity. Prefixes are established for designating multiple and submultiple units from "yotta" (10^{24}) down to "yocto" (10^{-24}) for convenience in writing and speaking.

C.1.3 Coherence of SI units

Another major advantage of SI is its coherence. Units might be chosen arbitrarily, but making an independent choice of a unit for each category of mutually comparable quantities would lead in general to the appearance of several additional numerical factors in the equations between the numerical values. It is possible, however, and in practice more convenient, to choose a system of units in such a way that the equations between numerical values, including the numerical factors, have exactly the same form as the corresponding equations between the quantities. A unit system defined in this way is called coherent with respect to the system of quantities and equations in question. Equations between units of a coherent unit system contain as numerical factors only the number 1.

C.2 Note concerning the liter

In 1795, the liter was intended to be identical with the cubic decimeter. The Third General Conference on Weights and Measures, meeting in 1901, decided to define the liter as the volume occupied by the mass of one kilogram of pure water at its maximum density under normal atmospheric pressure. Careful determinations in 1960 established the liter so defined as being equivalent to 1.000 028 dm^3. In 1964, the General Conference on Weights and Measures withdrew this definition of the liter and declared that the word *liter* may be employed as a special name for the cubic decimeter. Thus, its use is permitted with SI; but because its use in precision measurements might conflict with measurements recorded under the old definition, SI units are preferred in certain technical work or if coherent units are required.

C.3 Definitions of SI base units

Translations of the original French definitions of the seven base units of the International System of Units are given in C.3.1 through C.3.7.

C.3.1 meter: The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second. (Adopted by the 17th CGPM in 1983.)

C.3.2 kilogram: The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram. (Adopted by the 1st and 3rd CGPMs in 1889 and 1901.)

C.3.3 second: The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom. (Adopted by the 13th CGPM in 1967.)

C.3.4 ampere: The ampere is that constant current that, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed one meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length. (Adopted by the 9th CGPM in 1948.)

C.3.5 kelvin: The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. (Adopted by the 13th CGPM in 1967.)

NOTE—It follows from this definition that the temperature of the triple point of water is 273.16 K (0.01 °C). The freezing point of water at standard atmospheric pressure is approximately 0.01 K below the triple point of water.

C.3.6 mole: The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12. (Adopted by the 14th CGPM in 1971.)

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

C.3.7 candela: The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian. (Adopted by the 16th CGPM in 1979.)

C.4 Definitions of SI derived units with special names

Table C.1—SI derived units with special names

Physical quantity	Derived unit and definition
(1) Absorbed dose	The *gray* is the absorbed dose when the energy per unit mass imparted to matter by ionizing radiation is one joule per kilogram NOTE—The gray is also used for the ionizing radiation quantities: specific energy imparted, kerma, and absorbed dose index, which have the SI unit joule per kilogram.
(2) Activity	The *becquerel* is the activity of a radionuclide decaying at the rate of one spontaneous nuclear transition per second.
(3) Angle, plane	The *radian* is the plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius.
(4) Angle, solid	The *steradian* is the solid angle that, having its vertex in the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.
(5) Celsius temperature	The *degree Celsius* is equal to the kelvin and is used in place of the kelvin for expressing Celsius temperature (symbol t) defined by the equation $t = T - T_0$, where T is the thermodynamic temperature and $T_0 = 273.15$ K, by definition.
(6) Dose equivalent	The *sievert* is the dose equivalent when the absorbed dose of ionizing radiation multiplied by the dimensionless factors Q (quality factor) and N (product of any other multiplying factors), stipulated by the International Commission on Radiological Protection, is one joule per kilogram.
(7) 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.
(8) Electric charge	Electric charge is the time integral of electric current; its unit, the coulomb, is equal to the electric charge carried in one second by a current of one ampere.
(9) Electric conductance	The *siemens* is the electric conductance of a conductor in which a current of one ampere is produced by an electric potential difference of one volt.
(10) 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.
(11) Electric potential difference, electromotive force	The *volt* (unit of electric potential difference and electromotive force) is the difference of electric potential between two points of a conductor carrying a constant current of one ampere, when the power dissipated between these points is equal to one watt.
(12) 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.

Table C.1—SI derived units with special names (continued)

Physical quantity	Derived unit and definition
(13) Energy	The *joule* is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force.
(14) Force	The *newton* is that force that, when applied to a body having a mass of one kilogram, results in an acceleration of one meter per second squared.
(15) Frequency	The *hertz* is the frequency of a periodic phenomenon of which the period is one second.
(16) Illuminance	The *lux* is the illuminance produced by a luminous flux of one lumen uniformly distributed over a surface of one square meter.
(17) Catalytic activity	The *katal* is a rate of catalytic activity of one mole per second.
(18) Luminous flux	The *lumen* is the luminous flux emitted in a solid angle of one steradian by a point source having a uniform intensity of one candela.
(19) Magnetic flux	The *weber* is the magnetic flux that, linking a circuit of one turn, produces in it an electromotive force of one volt as the flux is reduced to zero at a uniform rate in one second.
(20) Magnetic flux density	The *tesla* is the magnetic flux density of one weber per square meter. The magnetic flux density is defined as an axial vector quantity such that the force exerted on an element of current is equal to the vector product of this element and the magnetic flux density. Thus, the tesla is also the magnetic flux density that produces a force of one newton on a one-meter length of wire carrying a current of one ampere, oriented normally to the flux density.
(21) Power	The *watt* is the power that represents a rate of energy transfer of one joule per second.
(22) Pressure or stress	The *pascal* is the pressure or stress of one newton per square meter.

SI derived units are only uniquely defined in terms of the base units [e.g., $1\ \Omega = 1\ \mathrm{m}^2 \cdot \mathrm{kg}/(\mathrm{s}^3 \cdot \mathrm{A}^2)$]. Thus, in some cases, the definition for a particular derived unit given here is just one of several possible definitions.

C.5 Comment on spelling

This standard uses the spellings “meter,” “liter,” and “deka.” The alternative spellings “metre,” “litre,” and “deca” may also be used.

C.6 Comments on mass, force, and weight

C.6.1 Distinction between units for mass and force

The names of mass units such as kilogram, pound, and ounce have often been erroneously used for units of force. This has led to serious confusion. In SI this confusion is eliminated because the unit of mass is the kilogram, and the unit of force is the newton. The kilogram-force (from which the suffix “force” in practice has often been erroneously dropped) is not used. Derived units that include force are formed using the newton.

C.6.2 Weight

The weight of a body in a particular reference frame is defined as the force that provides the body an acceleration equal to the local acceleration of free fall in that reference frame. Thus, the SI unit of weight is the newton (N).

In commercial and everyday use, the term “weight” is often used as a synonym for mass, for which the SI unit is the kilogram. The verb “to weigh” means “to determine the mass of” or “to have a mass of.” Nevertheless, in scientific and technical practice, the term “weight” should not be used to mean mass.

C.6.3 Load

The term *load* can mean mass, force, or pressure, depending on its use. A load arising from a vertical downward force because of the influence of gravitational force acting on a mass may be expressed in mass units, e.g., kilograms, but may also be expressed in terms of mass per unit area, or mass per unit length—for example the floor loading in a building in kilograms or kilograms per square meter. Load may also be expressed in terms of force, or force per unit area. A wind load may be best expressed as a force per unit length (N/m) or a force per unit area (i.e., a pressure, Pa).

C.6.4 Capacity rating

The capacity rating of a crane, a truck, a bridge, etc., is intended to define the mass that can be supported safely. Such a rating is expressed in a mass unit rather than a force unit, thus in kilograms or metric tons, as appropriate, rather than newtons.

Annex D

(informative)

Development of the International System of Units (SI)

D.1 History

The decimal system of units was conceived in the 16th century, when there was a great confusion and a jumble of units of weights and measures. It was not until 1790, however, that the French National Assembly requested that the French Academy of Sciences work out a system of units suitable for adoption by the entire world. This system was based on the meter as a unit of length. The mass of a cubic centimeter of water, the gram, was adopted as a practical measure to benefit industry and commerce. Physicists soon realized the system's 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. The metric system was legalized in this country in 1866. In 1893, the international meter and kilogram became the fundamental standards of length and mass in the U.S., both for metric and customary weights and measures.

Meanwhile, international standardization began with an 1870 meeting of 17 nations in Paris that led to the 20 May 1875 Convention du Mètre 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 meets at least every six years in Paris and controls the International Bureau of Weights and Measures, which in turn preserves the metric standards, compares national standards with them, and conducts research to establish new standards. The National Institute of Standards and Technology (NIST) represents the U.S. in these activities.

The metric system of 1875 provided a set of units for the measurement of length, area, volume, capacity, and mass. Measurement of additional quantities required for science and commerce has necessitated development of additional fundamental and derived units. Numerous other systems based on the meter and gram have been used. A unit of time was added to produce the centimeter-gram-second (CGS) system, adopted in 1881 by the International Electrical Congress. About the year 1900, practical measurements in metric units began to be based on the meter-kilogram-second (MKS) system. In 1935, the International Electrotechnical Commission (IEC) acted favorably on a proposal originally made by Professor Giovanni Giorgi in 1901 and 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 a fourth base unit. Subsequently the ampere, the unit of electric current, was selected as a base unit, thus defining the MKSA system.

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

The 15th CGPM in 1975 added prefixes for 10^{18} and 10^{15}, exa (E) and peta (P) respectively, and approved two special names: the gray (Gy) as a special name for the SI unit of absorbed dose, the joule per kilogram; and the becquerel (Bq) as a special name for the SI unit of activity of a radionuclide, one per second.

Because of the experimental difficulties in realizing a Planck radiator at high temperatures and the new possibilities offered by radiometry, i.e., the measurement of optical radiation power, the 16th CGPM in 1979 adopted a new definition of the SI base unit candela. It also adopted the special name sievert (Sv) for the SI unit of dose equivalent in the field of radioprotection. In order to increase the precision of realization of the SI base unit meter, the definition based upon the wavelength of a krypton-86 radiation was replaced by one based on the speed of light by the 17th CGPM in 1983. The 19th CGPM in 1991 added the prefixes zetta (Z) for 10^{21}, zepto (z) for 10^{-21}, yotta (Y) for 10^{24}, and yocto (y) for 10^{-24}.

When SI was established by the 11th CGPM in 1960, it had three classes of units: base units, derived units, and supplementary units. The class of supplementary units contained two units: the radian (rad) for plane angle and the steradian (sr) for solid angle. However, at the time of the introduction of the International System, the 11th CGPM left open the question of the nature of these supplementary units. Considering that plane angle is generally expressed as the ratio between two lengths and solid angle as the ratio between an area and the square of a length, in 1980 the CIPM (the International Committee for Weights and Measures of the CGPM) specified that in the International System the supplementary units radian and steradian are dimensionless derived units that may be used or omitted in expressing the values of physical quantities. This implies that the quantities plane angle and solid angle are considered dimensionless derived quantities.

Because of this interpretation, the 20th CGPM in 1995 eliminated supplementary units as a separate class in SI. Since then, SI consists of only two classes of units: base units and derived units, with the radian and steradian classified as derived units. The option of using them or not using them in expressions for other SI derived units, as is convenient, remains unchanged.

D.2 The International Bureau of Weights and Measures (BIPM)

The International Bureau of Weights and Measures (BIPM, Bureau International des Poids et Mesures) has its headquarters near Paris, in the grounds of the Pavillon de Breteuil (Parc de Saint-Cloud), placed at its disposal by the French Government; its upkeep is financed jointly by the member nations of the Convention du Mètre.

In September 2001, 51 nations were members of this Convention: Argentina (Republic of), Australia, Austria, Belgium, Brazil, Bulgaria, Cameroon, Canada, Chile, China (People's Republic of), Czech Republic, Denmark, Dominican Republic, Egypt, Finland, France, Germany, Greece, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Korea (Democratic People's Republic of), Korea (Republic of), Malaysia, Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Portugal, Romania, Russian Federation, Singapore, Slovakia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, the United States of America, Uruguay, Venezuela, and Yugoslavia.

The task of BIPM is to ensure worldwide unification of physical measurements; it is responsible for

— Establishing the fundamental standards and scales for measurement of the principal physical quantities and maintaining the international prototypes;
— Carrying out comparisons of national and international standards;
— Ensuring the coordination of corresponding measuring techniques;
— Carrying out and coordinating the determinations relating to the fundamental physical constants that are involved in the above-mentioned activities.

The BIPM operates under the exclusive supervision of the International Committee for Weights and Measures (CIPM, Comité International des Poids et Mesures), which itself comes under the authority of the General Conference on Weights and Measures (CGPM, Conférence Générale des Poids et Mesures).

The General Conference consists of delegates from all the member nations of the Convention du Mètre and meets at present every four years. At each meeting it receives the Report of the International Committee on the work accomplished, and it is responsible for

- Discussing and instigating the arrangements required to ensure the propagation and improvement of the International System of Units (SI, Système International d'Unités), which is the modern form of the metric system;
- Confirming the results of new fundamental metrological determinations and the various scientific resolutions of international scope;
- Adopting the important decisions concerning the organization and development of the BIPM.

Annex E

(informative)

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[3] The IEEE standards referred to in Annex E are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

[4] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

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INDEX

Table A.1, pp 20-33, lists many non-SI units in alphabetic order. For information on conversion of non-SI units to SI, that table should be consulted. This index does not contain entries from tables A.1 to A.7.