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

Co-Sponsors

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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 intended as a 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 10-1997, Standard for Use of the International System of Units (SI): The Modern Metric System. It is provided for information only.]

The International System of Units, defined in the document *Le Système International d'Unités* (and universally abbreviated SI), is the dominant system of measurement units used in much of the world with the exception of the United States. With the arrival of the global marketplace, it is now imperative for US industry to extend its use of SI and for US citizens to gain a working knowledge of this modern metric system. It is the purpose of this standard to provide engineers and scientists, as well as others who have need of it, information required to use SI in the internationally accepted manner.

Le Système International d'Unités is published by the International Bureau of Weights and Measures (BIPM). The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) publish international consensus standards relating to SI, which are founded on the BIPM document. (The ISO and IEC standards are listed in Annex E.) This standard conforms in substance with these documents with the following exceptions:

- a) The dot on the line instead of the comma is used as the decimal marker;
- b) Preference is given to the raised dot to indicate the product of two or more units; and
- c) The only units permitted for use temporarily with SI are nautical mile, knot, hectare, bar, barn, curie, roentgen, rad, and rem. The ångström, are, and gal are listed as units that are not to be used.

This standard incorporates the 1995 decision of the General Conference on Weights and Measures (CGPM) to eliminate the class of SI supplementary units, a decision that is too recent to be reflected in the current versions of the BIPM, ISO, and IEC publications.

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

1. Overview

This document is the primary American National Standard for use of the International System of Units, a system developed and maintained by the General Conference on Weights and Measures (abbreviated as CGPM from the official name, Conférence Générale des Poids et Mesures) as a basis for worldwide standardization of measurement units. The name International System of Units and the international abbreviation SI (from Le Système International d'Unités) were adopted by the 11th CGPM in 1960. SI is a complete, coherent system that is being universally adopted.

This document includes information on SI, a limited list of units recognized for use with SI, and a list of conversion factors, together with general guidance on style and usage.

2. SI units and symbols

2.1 Classes of units

SI units are divided into two classes: base units and derived units. Definitions of units are given in Annex C, Clauses C.3 and C.4.

2.2 Base units

SI is built upon the seven well-defined base units of Table 1, which by convention are regarded as independent. Note that in Table 1 and throughout this document the word “quantity” means a measurable attribute of a phenomenon or of matter.

2.3 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 mul-

tiplication, division, and use of exponents. For example, the SI unit for speed is the meter per second (m/s or $\text{m}\cdot\text{s}^{-1}$) and that for density is kilogram per cubic meter (kg/m^3 or $\text{kg}\cdot\text{m}^{-3}$).

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

* See 3.4.2 for a discussion of Celsius temperature.

Those SI derived units that have special names and symbols approved by the CGPM are listed in Tables 2 and 3. See Clause C.4 of Annex C for their definitions.

It is frequently advantageous to express derived units in terms of other derived units with special names; for example, the SI unit of surface tension is usually expressed as N/m instead of kg/s^2 and that for electric dipole moment is usually expressed as C·m instead of $\text{A}\cdot\text{s}\cdot\text{m}$.

Some common SI derived units without special names or symbols are listed in Table 4.

2.4 SI prefixes

The prefixes and symbols listed in Table 5 are used to form names and symbols of the decimal multiples and submultiples of the SI units, except for the kilogram (see 2.4.1). These prefixes or their symbols are attached to names or symbols of units, forming what are properly called “multiples and submultiples of SI units.” This designation is used in order to make a distinction between them and the coherent set of units (see Clause C.1 of Annex C) designated by the name “SI units,” namely, the base units and derived units. These coherent SI units and their multiples and submultiples are all units of the SI. For application of SI prefixes, see 3.2.

2.4.1 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 2—SI derived units with special names and symbols

Quantity	SI unit		
	Name	Symbol	Expression in terms of other SI units
angle, plane	radian*	rad	m/m = 1
angle, solid	steradian*	sr	m ² /m ² = 1
Celsius temperature†	degree Celsius	°C	K
electric capacitance	farad	F	C/V
electric charge, quantity of electricity	coulomb	C	A·s
electric conductance	siemens	S	A/V
electric inductance	henry	H	Wb/A
electric potential difference, electromotive force	volt	V	W/A
electric resistance	ohm	Ω	V/A
energy, work, quantity of heat	joule	J	N·m
force	newton	N	kg·m/s ²
frequency (of a periodic phenomenon)	hertz	Hz	1/s
illuminance	lux	lx	lm/m ²
luminous flux	lumen	lm	cd·sr
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m ²
power, radiant flux	watt	W	J/s
pressure, stress	pascal	Pa	N/m ²

* See the last paragraph of Clause D.1 of Annex D for a discussion about the previous classification of this unit.

† See 3.4.2 for a discussion of Celsius temperature.

Table 3—SI derived units with special names admitted for reasons of safeguarding human health

Quantity	SI unit		
	Name	Symbol	Expression in terms of other SI units
activity (of a radionuclide)	becquerel	Bq	1/s
absorbed dose, specific energy imparted, kerma, absorbed dose index	gray	Gy	J/kg
dose equivalent, dose equivalent index	sievert	Sv	J/kg

Table 4—Some common SI derived units without special names or symbols

Quantity	SI unit	
	Name	Symbol
absorbed dose rate	gray per second	Gy/s
acceleration	meter per second squared	m/s ²
angular acceleration	radian per second squared	rad/s ²
angular velocity	radian per second	rad/s
area	square meter	m ²
concentration (of amount of substance)	mole per cubic meter	mol/m ³
current density	ampere per square meter	A/m ²
density (mass density)	kilogram per cubic meter	kg/m ³
electric charge density	coulomb per cubic meter	C/m ³
electric field strength	volt per meter	V/m
electric flux density	coulomb per square meter	C/m ²
energy density	joule per cubic meter	J/m ³
entropy	joule per kelvin	J/K
exposure (x and gamma rays)	coulomb per kilogram	C/kg
heat capacity	joule per kelvin	J/K
heat flux density, irradiance	watt per square meter	W/m ²
luminance	candela per square meter	cd/m ²
magnetic field strength	ampere per meter	A/m
molar energy	joule per mole	J/mol
molar entropy	joule per mole kelvin	J/(mol·K)
molar heat capacity	joule per mole kelvin	J/(mol·K)
moment of force *	newton meter	N·m
permeability (magnetic)	henry per meter	H/m
permittivity	farad per meter	F/m
power density	watt per square meter	W/m ²
radiance	watt per square meter steradian	W/(m ² ·sr)
radiant intensity	watt per steradian	W/sr
specific heat capacity	joule per kilogram kelvin	J/(kg·K)
specific energy	joule per kilogram	J/kg
specific entropy	joule per kilogram kelvin	J/(kg·K)
specific volume	cubic meter per kilogram	m ³ /kg
surface tension	newton per meter	N/m
thermal conductivity	watt per meter kelvin	W/(m·K)
velocity	meter per second	m/s
viscosity, dynamic	pascal second	Pa·s
viscosity, kinematic	square meter per second	m ² /s
volume	cubic meter	m ³
wave number	1 per meter	1/m

* See 3.4.4.2.

Table 5—SI prefixes

Multiplication factor	Prefix	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

*See 3.2.2.

3. Use of 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. This clause gives guidance concerning 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 2.4) to indicate orders of magnitude. Thus, one can eliminate nonsignificant digits (i.e., 12 300 m becomes 12.3 km) and leading zeros in decimal fractions (i.e., 0.001 23 μ m becomes 1.23 nm). SI prefixes, therefore, provide a convenient alternative to the powers-of-ten notation preferred in computation (i.e., 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:

- In expressing area and volume, the prefixes hecto, deka, deci, and centi may be required; for example, cubic decimeter, square hectometer, cubic centimeter.
- 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.
- 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 Prefixes in compound units

A compound unit is a derived unit that is expressed in terms of two or more units, rather than by a single special name. Ordinarily, only one prefix should be used in forming a multiple or submultiple of a compound unit. Normally the prefix should be attached to a unit in the numerator. An exception to this is when the kilogram occurs in the denominator.

Examples:

kV/m is usually preferable to V/mm

MJ/kg is usually preferable to kJ/g

kg/m³ is usually preferable to g/cm³ (NOTE—1000 kg/m³ = 1 g/cm³)

3.2.4 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

If a value is required outside the range covered by the prefixes, express it by using a power of ten applied to the unit.

3.2.5 Powers of units

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

Examples:

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

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

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

3.2.6 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. This practice frequently leads to confusion and is deprecated.

3.3 Other units

3.3.1 Units from other systems

To preserve the advantage of SI as a coherent system, minimize the use of units from other systems with SI. Such use should be limited to units listed in this clause.

3.3.2 Units in use with SI (see Table 6)

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 necessary. For example, vehicle speed is often expressed in the unit kilometer per hour (km/h).

Table 6—Units in use with SI

Quantity	Unit	Symbol	Value in SI units
time	minute	min	1 min = 60 s
	hour	h	1 h = 60 min = 3600 s
	day	d	1 d = 24 h = 86 400 s
	week, month, etc.		
plane angle	degree [*]	°	1° = ($\pi/180$) rad
	minute [*]	'	1' = (1/60)° = ($\pi/10\,800$) rad
	second [*]	"	1" = (1/60)' = ($\pi/648\,000$) rad
volume	liter [†]	L, l	1 L = 1 dm ³ = 10 ⁻³ m ³
mass	metric ton or tonne [‡]	t	1 t = 10 ³ kg
Units whose values are obtained experimentally			
energy	electronvolt [§]	eV	1 eV = 1.602 177 33(49) × 10 ⁻¹⁹ J
mass	unified atomic mass unit [§]	u	1 u = 1.660 540 2(10) × 10 ⁻²⁷ kg

^{*} Decimal degrees should be used for division of degrees, except for fields such as astronomy and cartography.

[†] The symbol L is preferred for use in the United States. See 3.3.2.3.

[‡] The terms “metric ton” or “tonne” are restricted to commercial usage. See 3.3.2.4.

[§] The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum. The unified atomic mass unit equals 1/12 of the mass of an atom of the nuclide ¹²C. Values for eV and u are from *CODATA Bulletin Number 63* [B31]; the uncertainty of the last two figures, at the level of one standard deviation, is shown in parentheses.

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 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. In 1964, the CGPM declared that the word *liter* may be used as a special name for the cubic decimeter (dm^3). In addition, the CGPM recommended that the liter should not be used to express the results of high accuracy volume measurements.

In 1979, the CGPM approved 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 United States. Use of the script “ell” as a symbol for liter is deprecated. See Clause C.2 of Annex C for information concerning the history of this unit.

3.3.2.4 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, which is almost 2205 lb. None of these terms is SI. The terms “metric ton” and “tonne” are restricted to commercial usage.

3.3.2.5 Energy

The 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 electric energy. This unit should not be introduced into any new fields, and eventually it should be replaced. The unit to use is the megajoule.

3.3.3 Units in use temporarily with SI (see Table 7)

These units should not be introduced where they are not presently used.

3.3.3.1 Length

The nautical mile is a special unit employed for marine and aerial navigation to express distances. The conventional value given in Table 7 was adopted by the First International Extraordinary Hydrographic Conference, held in Monaco in 1929, under the name “International nautical mile.”

3.3.3.2 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).

3.3.4 Units and names that are not to be used

Table 8 lists deprecated units and, in many cases, units with which they may be replaced. These are examples of several metric and related units other than those of SI that have been defined over the years. These include all units defined only in the cgs, esu, and emu systems. Some of these are used only in special fields; others have found broad application outside the United States. Except for the special cases discussed in the previous clauses, do not use units that are not part of SI (as well as non-SI names for multiples or submultiples of

SI units, such as micron for micrometer). Units that are not to be used are discussed in more detail in 3.3.4.1 and 3.3.4.2. Note that these subclauses and Table 8 are not complete but only indicate prominent examples.

Table 7— Units in use temporarily with SI

Name	Symbol	Value in SI units
nautical mile		1 nautical mile = 1852 m
knot		1 nautical mile per hour = (1852/3600) m/s
hectare	ha	1 ha = 1 hm ² = 10 ⁴ m ²
bar*	bar	1 bar = 100 kPa
barn	b	1 b = 100 fm ² = 10 ⁻²⁸ m ²
curie	Ci	1 Ci = 3.7 × 10 ¹⁰ Bq
roentgen	R	1 R = 2.58 × 10 ⁻⁴ C/kg
rad	rad, rd [†]	1 rad = 1 cGy = 10 ⁻² Gy
rem	rem	1 rem = 1 cSv = 10 ⁻² Sv

*Usage is limited to meteorology.

†When there is risk of confusion with the symbol for radian, rd may be used as the symbol for rad.

3.3.4.1 Pressure and stress

The SI unit of pressure and stress is the pascal (newton per square meter), and with proper 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/cm²), or other non-SI units, such as torr and millimeter of mercury, for pressure. Because one bar equals 10⁵ Pa, the millibar should be called by its SI name, the hectopascal.

3.3.4.2 Centimeter-gram-second (CGS) units

Avoid all units with special names peculiar to the various cgs systems (measurement systems constructed by using the centimeter, gram, and second as base units). Among these units are the following, defined for mechanics, fluid mechanics, and photometry: the erg, dyne, gal, poise, stokes, stilb, phot, and lambert.

Further, avoid the cgs units of electricity and magnetism. This statement applies to the units designated by the general abbreviations “esu” (for electrostatic cgs unit) and “emu” (for electromagnetic cgs unit), including those units that have been given special names — the gauss, oersted, maxwell, gilbert, biot, and franklin. It also applies to the unit names formed with the prefixes ab and stat, for example, the abampere and statvolt.

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 Clause C.7 of Annex C.

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

Do not use		Value in SI units
Name	Symbol	
ångström	Å	= 0.1 nm = 10^{-10} m
are	a	= dam ² = 100 m ²
atmosphere, standard	atm	= 101.325 kPa
atmosphere, technical	at	= 98.0665 kPa
calorie (physics)*	cal	= 4.184 J
calorie (nutrition)*	Cal	= 4.184 kJ
candle		= cd
candlepower	cp	= cd
dyne	dyn	= 10^{-5} N
erg	erg	= 10^{-7} J
fermi	fermi	= fm = 10^{-15} m
G, g (as a unit)		= 9.806 65 m/s ²
gal	Gal	= cm/s ² = 10^{-2} m/s ²
gamma	γ	= nT = 10^{-9} T
gauss	G	= 10^{-4} T
gon, grad, grade	gon	= (π/200) rad
kilocalorie *	kcal	= 4.184 kJ
kilogram-force	kgf	= 9.806 65 N
kiloliter	1000 L	= m ³
langley	cal/cm ²	= 41.84 kJ/m ² = 4.184×10^4 J/m ²
maxwell	Mx	= 10^{-8} Wb
metric carat		= 200 mg = 2×10^{-4} kg
metric horsepower		≈ 735.5 W
micron	μ	= μm = 10^{-6} m
millimeter of mercury†	mmHg	≈ 133.3 Pa
millimeter, centimeter, or meter of water†	mmH ₂ O, etc.	= 9.806 65 Pa, etc.
millimicron	mμ	= nm = 10^{-9} m
mho	mho	= S

*See note [3] in A.4.2 of Annex A.

†See note [2] in A.4.2 of Annex A.

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

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

*See note [3] in A.4.2 of Annex A.

†See note [2] in A.4.2 of Annex A.

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 ($^{\circ}\text{C}$), which is equal to the unit kelvin; it 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) [B30]¹ 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 by 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, nominal metric designations as deemed appropriate. (Note that the term “dimension” as used in this paragraph is defined in Clause B.1 of Annex B and differs from its use in 3.4.8.)

¹The numbers in brackets refer to the bibliography in Annex E.

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 SI units of the quantities angle, angular velocity, and angular acceleration are, respectively, 1, 1/s, and 1/s². 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/s² 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). (See Clause C.5 of Annex C for an additional discussion of angle.)

3.4.4.2 Moment of force (bending moment)

Because moment of force (bending moment) and torque are equal to a force times a distance (moment arm or lever arm), their SI unit is N·m. The joule (J), which is a special name for the SI unit of energy and work, N·m, shall not be used as a name for the unit of moment of force or of torque. (See also 3.4.7.)

3.4.4.3 Moment of inertia

This quantity (I) is a property of the mass distribution of a body about an axis ($I = \Sigma mr^2$); its SI unit is kg·m².

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·m²/s. The total angular momentum of a body of moment of inertia I (SI unit kg·m²) rotating with angular velocity ω (SI unit 1/s) is $I\omega$ (SI unit kg·m²/s).

3.4.4.5 Kinetic energy

The kinetic energy of a body of moment of inertia I (SI unit kg·m²) rotating with angular velocity ω (SI unit 1/s) is $I\omega^2/2$; its SI unit is J.

3.4.5 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 force and moment arm, but no such distinction is possible in the associated units.

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 negative gage pressure or absolute 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, $\text{m/m} = 1$). More generally, a quantity of dimension one may be expressed by the ratio of units (for example, $\text{mm/m} = 10^{-3}$). 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 names of numbers one billion and larger are not uniform worldwide, do not use terms such as parts per billion and parts per trillion. (See 3.5.4.2.)

When expressing the values of quantities of dimension one, the meaning has to be clear. Expressions like “The mass fraction of Pt in the sample is 90% (or 0.9),” “the volume fraction of CO_2 in the sample is 1.2×10^{-6} ,” 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,” “volume,” and “amount of substance,” respectively, were not in the three expressions. These three fractions can also be expressed as 0.9 kg/kg , $1.2 \text{ cm}^3/\text{m}^3$, 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. Because unit symbols are not abbreviations, they are written according to rules developed by international agreement.

- a) Print unit symbols in roman (upright) type regardless of the type style used in the surrounding text.
- 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) Write letter unit symbols in lowercase (for example, cd) unless the unit name has been derived from a proper name, in which case the first letter of the symbol is capitalized (for example, W, Pa). The exception is the symbol for liter, L. Prefix symbols use either lowercase or uppercase letters as shown in 2.4. Unit symbols retain their prescribed form regardless of the surrounding typography.
- e) 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.

- f) Do not leave any space between the prefix and unit symbols.
- g) Use symbols, not 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 Clause C.6 in Annex C regarding spelling.) The following rules should be followed in the United States:

- 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) 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 commonly 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.

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

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

For limited character sets where the raised dot is not possible, use a space. In the case of $\text{kW}\cdot\text{h}$, kilowatthour (a non-SI unit), the raised dot is often omitted, as is the space; thus, kWh.

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

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

Do not use more than one solidus in the same expression unless parentheses are inserted to avoid ambiguity. For example, write

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

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 *nor* joules/kg *nor* $\text{joules}\cdot\text{kg}^{-1}$

3.5.4 Numbers

3.5.4.1 Decimal marker

In the United States, the decimal marker is a dot on the line. When writing numbers less than one, write a zero before the decimal marker.

Outside the United States, the comma is widely used as the decimal marker. In some applications, therefore, the common practice in the United States of using the comma to separate digits into groups of three (as in 23,478) may cause ambiguity. To avoid this potential source of confusion, recommended 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 to separate groups of numbers is not customary.

3.5.4.2 Billion

Because billion means a thousand million (prefix giga) in the United States but a million million (prefix tera) in most other countries, avoid the term and similar terms for larger numbers in technical writing.

3.5.4.3 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,” nor “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. Use instead “...at a gage pressure of 13 kPa” or “...at an absolute pressure of 13 kPa.”

Where space is limited, such as on gages, nameplates, graph labels, and in table headings, the use of a modifier in parentheses, such as “kPa (gage),” “kPa (absolute),” or “V (ac),” is 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.