

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)



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

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

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 m μm

2.4 pF, *not* 2.4 $\mu\mu\text{F}$

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:

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

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

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

3.2.5 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 = 2 π rad
area	hectare	ha	ha = 1 hm ² = 10 ⁴ m ²
volume	liter ^b	L	L = 1 dm ³ = 10 ⁻³ m ³
mass	metric ton	t	t = 1 Mg = 10 ³ kg

^aDecimal degrees should be used for division of degrees, except for fields such as astronomy and cartography.

^bSee 3.3.2.4.

¹The 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

$$1 \text{ KiB} = 2^{10} \text{ B} = 1024 \text{ B}.$$

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	$eV = 1.602\,176\,462(63) \times 10^{-19} \text{ J}$
mass	unified atomic mass unit ^c	u	$u = 1.660\,538\,73(13) \times 10^{-27} \text{ kg}$

^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 ¹²C, 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 (m²). The hectare (ha) is a special name for the square hectometer (hm²). Large land or water areas are generally expressed in hectares or in square kilometers (km²). 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 (m³). Use this unit, or a multiple or submultiple of it, such as cubic kilometer (km³), cubic centimeter (cm³), etc. The liter is a special name for the cubic decimeter (dm³). 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 m/s ²
gal	Gal	Gal = cm/s ² = 10^{-2} 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	cal/cm ²	cal/cm ² = 41.84 kJ/m ² = 4.184×10^4 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	mmH ₂ O, 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	$Oe = (1000/4\pi) \text{ A/m}$
phot	ph	$ph = 10^4 \text{ lx}$
poise	P	$P = \text{dyn} \cdot \text{s/cm}^2 = 0.1 \text{ Pa} \cdot \text{s}$
stere	st	$st = \text{m}^3$
stilb	sb	$sb = \text{cd/cm}^2 = 10^4 \text{ cd/m}^2$
stokes	St	$St = \text{cm}^2/\text{s} = 10^{-4} \text{ m}^2/\text{s}$
torr	Torr	$\text{Torr} = (101\,325/760) \text{ Pa}$
x unit		$1.0021 \times 10^{-13} \text{ m}$
γ (mass)	γ	$\gamma = \mu\text{g} = 10^{-9} \text{ kg}$
λ (volume)	λ	$\lambda = \text{mm}^3 = 10^{-9} \text{ m}^3$

^aSee note [3] in Table A.1 for a note on the calorie and kilocalorie.

^bSee 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,

²The 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/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).

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 · 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 Rotational 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.

3.4.4.6 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, $\text{m/m} = 1$). 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 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