*Recognized as an*
American National Standard (ANSI)

**IEEE/ASTM SI 10-1997**
(Revision and redesignation of
ANSI/IEEE Std 268-1992 and ASTM E 380-93)

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

Co-Sponsors

**ASTM Committee E-43 on SI Practice**

and

**IEEE Standards Coordinating Committee 14 on Quantities, Units, and Letter Symbols**

Approved 26 February 1997

**American Society for Testing and Materials**

Approved 20 March 1997

**IEEE Standards Board**

Approved 1 April 1997

**American National Standards Institute**

**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

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA



ISBN 1-55937-901-4

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

American Society for Testing and Materials
(ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
USA

# 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.

**Bruce B. Barrow,** *Chairman*, IEEE SCC14 (Quantities, Units, and Letter Symbols)
**Oliver K. Lewis,** *Co-Chairman,* ASTM Committee E-43 (SI Practice)

This standard was developed by the joint IEEE/ASTM Editorial Task Group under the guidance of IEEE SCC14, Quantities, Units, and Letter Symbols, and ASTM Committee E-43, SI Practice.

| | |
|---|---|
| Robert H. Bushnell | John T. Scott |
| Robert A. Parsons | Barry N. Taylor |

Mary Lynne Nielsen
*IEEE Standards Project Editor*

# Contents

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

**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 A·s·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 | $kg \cdot m/s^2$ |
| 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 µm becomes 1.23 nm). SI prefixes, therefore, provide a convenient alternative to the powers-of-ten notation preferred in computation (i.e., $12.3 \times 10^3$ 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 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

$kg/m^3$ is usually preferable to $g/cm^3$ (NOTE—1000 $kg/m^3$ = 1 $g/cm^3$)

### 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:*

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

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

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

### 3.2.6 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° = (π/180) rad |
| | minute* | ' | 1' = (1/60)° = (π/10 800) rad |
| | second* | " | 1" = (1/60)' = (π/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 $^{12}C$. 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 = $3.7 \times 10^{10}$ Bq |
| roentgen | R | 1 R = $2.58 \times 10^{-4}$ 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 ($kgf/cm^2$), or other non-SI units, such as torr and millimeter of mercury, for pressure. Because one bar equals $10^5$ 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 | $\gamma$ | = nT = $10^{-9}$ T |
| gauss | G | = $10^{-4}$ T |
| gon, grad, grade | gon | = ($\pi$/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 | $\mu$ | = $\mu$m = $10^{-6}$ m |
| millimeter of mercury† | mmHg | ≈ 133.3 Pa |
| millimeter, centimeter, or meter of water† | $mmH_2O$, etc. | = 9.806 65 Pa, etc. |
| millimicron | m$\mu$ | = 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 | $= (1000/4\pi)$ A/m |
| phot | ph | $= 10^4$ lx |
| poise | P | = dyn·s/cm$^2$ = 0.1 Pa·s |
| stere | st | = m$^3$ |
| stilb | sb | = cd/cm$^2$ = $10^4$ cd/m$^2$ |
| stokes | St | = cm$^2$/s = $10^{-4}$ m$^2$/s |
| torr | Torr | = (101 325/760) Pa |
| x unit | | $\approx 1.0021 \times 10^{-13}$ m |
| $\gamma$ (mass) | $\gamma$ | = $\mu$g = $10^{-9}$ kg |
| $\lambda$ (volume) | $\lambda$ | = mm$^3$ = $10^{-9}$ 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 (°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

$t = T - T_0$, where $T_0 = 273.15$ 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.)

[1]The 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 $1/s^2$. 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). (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 $kg \cdot m^2$.

#### 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 $\omega$ (SI unit 1/s) is $I\omega$ (SI unit $kg \cdot m^2/s$).

#### 3.4.4.5 Kinetic energy

The kinetic energy of a body of moment of inertia $I$ (SI unit $kg \cdot m^2$) rotating with angular velocity $\omega$ (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, 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 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 $1.2 \times 10^{-6}$,” or “the amount-of-substance fraction of Pb in the sample is $2.7 \times 10^{-3}$,” 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 $cm^3/m^3$, 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

N·m *or* N m

For limited character sets where the raised dot is not possible, use a space. In the case of kW·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:

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

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

J/(mol·K) *or* $\mathrm{J \cdot mol^{-1} \cdot K^{-1}}$ *or* (J/mol)/K, but *not* 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 *nor* joules/kg *nor* $\mathrm{joules \cdot kg^{-1}}$

### 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.

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 4 kg and 1 ft = 0.3048 m (exactly)

By substitution, 1 lb·ft/s = (0.453 592 4 kg)·(0.3048 m/s) = 0.138 255 0 kg·m/s and the desired conversion factor is 0.138 255 0

Note that the seventh decimal place in this conversion factor (i.e., the last zero) is significant, because the relation 1 ft = 0.3048 m is exact.

## A.4 Tables

### A.4.1 Organization

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

| | |
|---|---|
| Table A.2 | Space and time |
| Table A.3 | Mechanics |
| Table A.4 | Heat |
| Table A.5 | Electricity and magnetism |
| Table A.6 | Radiology |
| Table A.7 | Light |

### A.4.2 Notes

Numbers that appear in square brackets in the note column in the tables refer to the following notes:

[1] The US Metric Law of 1866 gave the relationship 1 meter equals 39.37 inches. Since 1893, the US yard has been derived from the meter. In 1959, a refinement was made in the definition of the yard to bring the US yard and the yard used in other countries into agreement. The US 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 United States would remain with the old standard (1 foot = 1200/3937 meter). This foot is named the US survey foot. Lengths, areas, and volumes based on the US 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 acceleration of free fall 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 standard acceleration of free fall ($g_n$ = 9.806 65 m/s$^2$), 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. Other conversion factors for 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 calories 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] The therm (EEC) was legally defined in the Council Directive of December 20, 1979, Council of the European Economic Communities, now the European Union. The therm (US) is legally defined in the Federal Register of July 27, 1968. Although the therm (EEC), which is based on the International Table Btu, is frequently used by engineers in the United States, the therm (US) is the legal unit used by the natural gas industry in the United States.

[5] In most 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 US gallon.

[6] Agricultural products are sold by the bushel in the United States. 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 United States 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 6.

## Table A.1—Alphabetical list of units

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| 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 (Ω) | **1.0 E−09** | |
| abvolt | volt (V) | **1.0 E−08** | |
| acre (43 560 square US survey feet) | square meter ($m^2$) | 4 046.873 | [1] |
| acre-foot | cubic meter ($m^3$) | 1 233.5 | |
| ampere hour | coulomb (C) | **3 600** | |
| ångström | meter (m)<br>nanometer (nm) | **1.0 E−10**<br>**0.1** | |
| are | square meter ($m^2$) | **100** | |
| astronomical unit | meter (m) | 1.495 979 E+11 | |
| atmosphere, standard | pascal (Pa)<br>kilopascal (kPa) | **1.013 25 E+05**<br>**101.325** | [2] |
| atmosphere, technical (1 kgf/$cm^2$) | pascal (Pa)<br>kilopascal (kPa) | **9.806 65 E+04**<br>**98.066 5** | [2] |
| bar | pascal (Pa)<br>kilopascal (kPa) | **1.0 E+05**<br>**100** | |
| barn | square meter ($m^2$) | **1.0 E−28** | |
| barrel (oil, 42 US gallons) | cubic meter ($m^3$)<br>liter (L) | 0.158 987 3<br>158.987 3 | |
| biot (see also abampere) | ampere (A) | **10** | |
| board foot | See note [9] | — | [9] |
| British thermal unit (Btu) (International Table) | joule (J) | 1 055.056 | [3] |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| British thermal unit (Btu) (thermochemical) | joule (J) | 1 054.350 | [3] |
| Btu foot per hour square foot degree Fahrenheit [Btu·ft/(h·ft$^2$·°F)] | watt per meter kelvin [W/(m·K)] | 1.730 735 | [3] |
| Btu inch per hour square foot degree Fahrenheit [Btu·in/(h·ft$^2$·°F)] | watt per meter kelvin [W/(m·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) | 1 899.101 | [3] |
| Btu per degree Rankine (Btu/°R) | joule per kelvin (J/K) | 1 899.101 | [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 [W/(m$^2$·K)] | 5.678 263 | [3] |
| Btu per pound (Btu/lb) | joule per kilogram (J/kg) | **2 326** | [3] |
| Btu per pound degree Fahrenheit [Btu/(lb·°F)] | joule per kilogram kelvin [J/(kg·K)] | **4 186.8** | [3] |
| Btu per second (Btu/s) | watt (W) | 1 055.056 | [3] |
| Btu per square foot (Btu/ft$^2$) | joule per square meter (J/m$^2$) | 1.135 653 E+04 | [3] |
| bushel (US dry) | cubic meter (m$^3$) | 0.035 239 07 | [6] |
| calorie (thermochemical) | joule (J) | **4.184** | [3] |
| calorie, nutrition (kilocalorie) | joule (J) | **4 184** | [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) | **4 184** | [3] |
| calorie per gram degree Celsius [cal/(g·°C)] | joule per kilogram kelvin [J/(kg·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] |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| 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$^2$) | 1 550.003 | |
| candle, candlepower | candela (cd) | **1.0** | |
| carat (metric) | kilogram (kg)<br>gram (g) | **0.000 2**<br>**0.2** | |
| centimeter of water | pascal (Pa) | **98.066 5** | [2] |
| centipoise | pascal second (Pa·s) | **0.001** | |
| centistokes | square meter per second (m$^2$/s) | **1.0 E−06** | |
| chain (66 US survey feet) | meter (m) | 20.116 84 | [1] |
| circular mil | square millimeter (mm$^2$) | 5.067 075 E−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)<br>liter per second (L/s) | 4.719 474 E−04<br>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 | cubic meter (m$^3$)<br>cubic kilometer (km$^3$) | 4.168 182 E+09<br>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 (US) | cubic meter (m$^3$)<br>liter (L)<br>milliliter (mL) | 2.366 E−04<br>0.236 6<br>236.6 | |
| curie | becquerel (Bq) | **3.7 E+10** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| dalton | kilogram (kg) | 1.660 540 E−27 | |
| darcy | square meter ($m^2$) | 9.869 233 E−13 | [7] |
| day (mean solar) | second (s) | **8.64 E+04** | |
| day (sidereal) | second (s) | 8.616 409 E+04 | |
| degree | radian (rad) | **π/180 = 0.017 453 29** | |
| degree Celsius (°C) (interval) | kelvin (K) | **1.0** | |
| degree Celsius (°C) (temperature) | kelvin (K) | $T_K = t_{°C} + \mathbf{273.15}$ | |
| degree centigrade (interval) | degree Celsius (°C) | 1.0 | |
| degree centigrade (temperature) | degree Celsius (°C) | $t_{°C} \approx t_{centigrade}$ | |
| degree Fahrenheit (°F) (interval) | kelvin (K)<br>degree Celsius (°C) | 0.555 555 6<br>0.555 555 6 | |
| degree Fahrenheit (°F) (temperature) | kelvin (K)<br>degree Celsius (°C) | $T_K = (t_{°F} + \mathbf{459.67)/1.8}$<br>$t_{°C} = (t_{°F} - \mathbf{32)/1.8}$ | |
| 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) | $T_K = T_{°R}/\mathbf{1.8}$ | |
| denier | kilogram per meter (kg/m) | 1.111 111 E−07 | |
| dyne | newton (N) | **1.0 E−05** | |
| dyne centimeter | newton meter (N·m) | **1.0 E−07** | |
| dyne per square centimeter | pascal (Pa) | **0.1** | |
| electronvolt | joule (J) | 1.602 19 E−19 | [10] |
| erg | joule (J) | **1.0 E−07** | |
| erg per second | watt (W) | **1.0 E−07** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| erg per square centimeter | watt 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)<br>femtometer (fm) | **1.0 E−15**<br>**1.0** | |
| foot | meter (m) | **0.304 8** | |
| foot, US survey | meter (m) | 0.304 800 6 | [1] |
| foot of water | pascal (Pa)<br>kilopascal (kPa) | 2 989.07<br>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 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 poundal | joule (J) | 0.042 140 11 | |
| footcandle | lux (lx) | 10.763 91 | |
| footlambert | candela per square meter (cd/m$^2$) | 3.426 259 | |
| franklin | coulomb (C) | 3.335 641 E−10 | |
| $g_n$ (standard acceleration of free fall) | meter per second squared (m/s$^2$) | **9.806 65** | |
| gal | meter per second squared (m/s$^2$) | **0.01** | |
| gallon (Imperial) | cubic meter (m$^3$)<br>liter (L) | 4.546 09 E−03<br>4.546 09 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| gallon (US) (231 in$^3$) | cubic meter (m$^3$) | 3.785 412 E−03 | |
| | liter (L) | 3.785 412 | |
| gallon (US) per day | cubic meter per second (m$^3$/s) | 4.381 264 E−08 | |
| | liter per second (L/s) | 4.381 264 E−05 | |
| gallon (US) per minute (gpm) | cubic meter per second (m$^3$/s) | 6.309 020 E−05 | |
| | liter per second (L/s) | 0.063 090 20 | |
| gallon (US) per horsepower hour | cubic meter per joule (m$^3$/J) | 1.410 089 E−09 | |
| gamma | tesla (T) | **1.0 E−09** | |
| gauss | tesla (T) | **1.0 E−04** | |
| gilbert | ampere (A) | 0.795 774 7 | |
| gill (US) | cubic meter (m$^3$) | 1.182 941 E−04 | |
| grad, grade, gon | radian (rad) | **2π/400 = 0.015 707 96** | |
| | degree of angle (°) | **0.9** | |
| grain | kilogram (kg) | **6.479 891 E−05** | |
| | milligram (mg) | **64.798 91** | |
| grain per gallon (US) | kilogram per cubic meter (kg/m$^3$) | 0.017 118 06 | |
| | milligram per liter (mg/L) | 17.118 06 | |
| hectare | square meter (m$^2$) | **1.0 E+04** | |
| horsepower (550 ft·lbf/s) | watt (W) | 745.699 9 | |
| horsepower (boiler) (approximately 33 470 Btu/h) | watt (W) | 9 809.50 | |
| horsepower (electric) | watt (W) | **746** | |
| horsepower (metric) | watt (W) | 735.498 8 | |
| horsepower (water) | watt (W) | 746.043 | |
| hour | second (s) | **3 600** | |
| hour (sidereal) | second (s) | 3 590.170 | |
| hundredweight, long (112 lb) | kilogram (kg) | 50.802 35 | |
| hundredweight, short (100 lb) | kilogram (kg) | 45.359 24 | |
| inch | meter (m) | **0.025 4** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| inch of mercury | pascal (Pa)<br>kilopascal (kPa) | 3 386.39<br>3.386 39 | [2] |
| inch of water | pascal (Pa) | 249.089 | [2] |
| inch ounce-force | newton meter (N·m)<br>millinewton meter (mN·m) | 7.061 552 E–03<br>7.061 552 | |
| 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** | |
| kelvin (K) (temperature) | degree Celsius (°C) | $t_{°C} = T_K$ **– 273.15** | |
| kilocalorie (thermochemical) | joule (J) | **4 184** | [3] |
| kilogram-force | newton (N) | **9.806 65** | |
| kilogram-force meter | newton meter (N·m) | **9.806 65** | |
| kilogram-force per square centimeter | kilopascal (kPa) | **98.066 5** | |
| kilogram-force per square meter | pascal (Pa) | **9.806 65** | |
| kilometer per hour | meter per second (m/s) | **1000/3600 = 0.277 777 8** | |
| kilopond (kilogram-force) | newton (N) | **9.806 65** | |
| kilowatthour | joule (J)<br>megajoule (MJ) | **3.6 E+06**<br>**3.6** | |
| kip (1000 lbf) | kilonewton (kN) | 4.448 222 | |
| kip per square inch (ksi) | kilopascal (kPa) | 6 894.757 | |
| knot (nautical mile per hour) | meter per second (m/s) | 0.514 444 4 | |
| lambert | candela per square meter (cd/m$^2$) | **(1/π) E+04 = 3 183.099** | |
| langley (cal/cm$^2$) | joule per square meter (J/m$^2$) | **4.184 E+04** | |
| light year | meter (m) | 9.460 528 E+15 | |
| liter | cubic meter (m$^3$) | **0.001** | |
| lumen per square foot | lumen per square meter (lm/m$^2$) | 10.763 91 | |
| maxwell | weber (Wb) | **1.0 E–08** | |
| mho | siemens (S) | **1.0** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| microinch | meter (m)<br>micrometer (μm) | **2.54 E−08**<br>**0.025 4** | |
| micron | meter (m)<br>micrometer (μm) | **1.0 E−06**<br>**1.0** | |
| mil (0.001 in) | meter (m)<br>millimeter (mm) | **2.54 E−05**<br>**0.025 4** | [8] |
| mil (angle) | radian (rad)<br>degree (˚) | **2π/6400 = 9.817 477 E−04**<br>**0.056 25** | |
| mile, international (5280 ft) | meter (m) | **1 609.344** | |
| mile, nautical | meter (m) | **1 852** | |
| mile, US statute | meter (m) | 1 609.347 | [1] |
| mile per gallon (US) (mpg) | meter per cubic meter ($m/m^3$)<br>kilometer per liter (km/L)<br>liter per 100 kilometers (L/100 km) | 4.251 437 E+05<br>0.425 143 7<br>divide 235.215 by the number of miles per gallon | [5] |
| mile per hour | meter per second (m/s)<br>kilometer per hour (km/h) | **0.447 04**<br>**1.609 344** | |
| mile per minute | meter per second (m/s) | **26.822 4** | |
| millibar | pascal (Pa)<br>kilopascal (kPa) | **100**<br>**0.1** | |
| millimeter of mercury | 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 | |
| oersted | ampere per meter (A/m) | 79.577 47 | |
| ohm centimeter | ohm meter (Ω·m) | **0.01** | |
| ohm circular-mil per foot | ohm meter (Ω·m)<br>ohm square millimeter per meter ($\Omega \cdot mm^2/m$) | 1.662 426 E−09<br>0.001 662 426 | |
| ounce (avoirdupois) | kilogram (kg)<br>gram (g) | 0.028 349 52<br>28.349 52 | |
| ounce (Imperial fluid) | cubic meter ($m^3$)<br>milliliter (mL) | 2.841 306 E−05<br>28.413 06 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| ounce (troy or apothecary) | kilogram<br>gram (g) | 0.031 134 8<br>31.103 48 | |
| ounce (US fluid) | cubic meter ($m^3$)<br>milliliter (mL) | 2.957 353 E−05<br>29.573 53 | |
| ounce-force | newton (N) | 0.278 013 9 | |
| ounce (av) per cubic inch ($oz/in^3$) | kilogram per cubic meter ($kg/m^3$) | 1 729.994 | |
| ounce (av) per gallon (US) (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 | meter (m) | 3.085 678 E+16 | |
| peck (US dry) | cubic meter ($m^3$)<br>liter (L) | 8.809 768 E−03<br>8.809 768 | |
| pennyweight | kilogram (kg)<br>gram (g) | 1.555 174 E−03<br>1.555 174 | |
| perm (0 °C) | kilogram per pascal second square meter [$kg/(Pa{\cdot}s{\cdot}m^2)$] | 5.721 35 E−11 | |
| perm (23 °C) | kilogram per pascal second square meter [$kg/(Pa{\cdot}s{\cdot}m^2)$] | 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 | lumen per square meter ($lm/m^2$) | **1.0 E+04** | |
| pica (computer) (1/6 in) | meter (m)<br>millimeter (mm) | 0.004 233 333<br>4.233 333 | |
| pica (printer’s) | meter (m)<br>millimeter (mm) | 0.004 217 5<br>4.217 5 | |
| pint (Imperial) | cubic meter ($m^3$)<br>liter (L) | **5.682 612 5 E−04**<br>**0.568 261 25** | |
| pint (US dry) | cubic meter ($m^3$)<br>liter (L) | 5.506 1 E−04<br>0.550 61 | |
| pint (US liquid) | cubic meter ($m^3$)<br>liter (L) | 4.731 76 E−04<br>0.473 176 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| point (computer) (1/72 in) | meter (m)<br>millimeter (mm) | 3.527 778 E−04<br>0.352 777 8 | |
| point (printer's) | meter (m)<br>millimeter (mm) | 3.514 6 E-04<br>0.351 46 | |
| poise | pascal second (Pa·s) | **0.1** | |
| pound (avoirdupois) | kilogram (kg) | **0.453 592 37** | |
| pound (troy or apothecary) | kilogram (kg) | 0.373 241 7 | |
| poundal | newton (N) | 0.138 255 0 | |
| poundal per square foot | pascal (Pa) | 1.488 164 | |
| pound-force | newton (N) | 4.448 222 | |
| pound-force foot (lbf·ft) (torque) | newton meter (N·m) | 1.355 818 | |
| 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)<br>kilopascal (kPa) | 6 894.757<br>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) | 6 894.757 | |
| 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 (US) (lb/gal) | kilogram per cubic meter ($kg/m^3$)<br>kilogram per liter (kg/L) | 119.826 4<br>0.119 826 4 | |
| pound per hour (lb/h) | kilogram per second (kg/s) | 1.259 979 E−04 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| 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 square foot | 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 | joule (J) | 1.055 E+18 | |
| quart (US dry) | cubic meter ($m^3$)<br>liter (L) | 0.001 101 221<br>1.101 221 | |
| quart (US liquid) | cubic meter ($m^3$)<br>liter (L) | 9.463 529 E−04<br>0.946 352 9 | |
| rad (absorbed dose) | gray (Gy) | **0.01** | |
| rem (dose equivalent) | sievert (Sv) | **0.01** | |
| revolution | 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 US survey feet) | meter (m) | 5.029 210 | [1] |
| roentgen | 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)<br>nanosecond (ns) | **1.0 E−08**<br>**10** | |
| slug | kilogram (kg) | 14.593 90 | |
| 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 | square meter ($m^2$) | 2.589 988 E+06 | |
| square yard ($yd^2$) | square meter ($m^2$) | 0.836 127 4 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| 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 | cubic meter ($m^3$) | **1.0** | |
| stilb | candela per square meter ($cd/m^2$) | **1.0 E+04** | |
| stokes | square meter per second ($m^2/s$) | **1.0 E−04** | |
| tablespoon | cubic meter ($m^3$)<br>milliliter (mL) | 1.479 E−05<br>14.79 | |
| teaspoon | cubic meter ($m^3$)<br>milliliter (mL) | 4.929 E−06<br>4.929 | |
| tex | kilogram per meter (kg/m) | **1.0 E−06** | |
| therm (EEC) | joule (J) | **1.055 06 E+08** | [4] |
| therm (US) | joule (J) | **1.054 804 E+08** | [4] |
| ton, assay | gram (g) | 29.166 67 | |
| ton, long (2240 lb) | kilogram (kg) | 1 016.047 | |
| ton, metric | kilogram (kg) | **1 000** | |
| tonne | kilogram (kg) | **1 000** | |
| ton, register | cubic meter ($m^3$) | 2.831 685 | |
| ton, short (2000 lb) | kilogram (kg) | 907.184 7 | |
| ton (from energy equivalent of one ton of TNT) ($10^6$ 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) | 3 516.853 | [3] |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| ton (long) per cubic yard | kilogram per cubic meter ($kg/m^3$) | 1 328.939 | |
| ton (short) per cubic yard | kilogram per cubic meter ($kg/m^3$) | 1 186.553 | |
| ton (short) per hour | kilogram per second (kg/s) | 0.251 995 8 | |
| torr | pascal (Pa) | 133.322 | |
| unified atomic mass unit (u) | kilogram (kg) | 1.660 540 E−27 | [10] |
| unit pole | weber (Wb) | 1.256 637 E−07 | |
| watt hour | joule (J) | **3 600** | |
| 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 ($W/m^2$) | 1 550.003 | |
| watt second | joule (J) | **1.0** | |
| yard | meter (m) | **0.914 4** | |
| year of 365 days | 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 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| | ***Angle*** | | |
| degree | radian (rad) | **π/180** = 0.017 453 29 | |
| grad, grade, gon | degree of angle (°)<br>radian (rad) | **0.9**<br>**0.9π/180** = 0.015 707 96 | |
| mil | radian (rad)<br>degree (˚) | **2π/6400** = 9.817 477 E–04<br>**0.056 25** | |
| minute (arc) | radian (rad) | 2.908 882 E–04 | |
| revolution | radian (rad) | **2π =** 6.283 185 | |
| second | radian (rad) | 4.848 137 E–06 | |
| | ***Length*** | | |
| ångström | meter (m)<br>nanometer (nm) | **1.0 E–10**<br>**0.1** | |
| astronomical unit | meter (m) | 1.495 979 E+11 | |
| chain (66 US survey feet) | meter (m) | 20.116 84 | [1] |
| fathom | meter (m) | 1.828 8 | |
| fermi | meter (m)<br>femtometer (fm) | **1.0 E–15**<br>**1.0** | |
| foot | meter (m) | **0.304 8** | |
| foot, US survey | meter (m) | 0.304 800 6 | [1] |
| inch | meter (m) | **0.025 4** | |
| light year | meter (m) | 9.460 528 E+15 | |
| microinch | meter (m)<br>micrometer (μm) | **2.54 E–08**<br>**0.025 4** | |
| micron | meter (m)<br>micrometer (μm) | **1.0 E–06**<br>**1.0** | |
| mil (0.001 in) | meter (m)<br>millimeter (mm) | **2.54 E–05**<br>**0.025 4** | |
| mile, international (5280 ft) | meter (m) | **1 609.344** | |
| mile, nautical | meter (m) | **1 852** | |

1 A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
2 Numbers in the Note column refer to A.4.2.

**Table A.2—Classified list of units—space and time *(continued)***

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| mile, US statute | meter (m) | 1 609.347 | [1] |
| parsec | meter (m) | 3.085 678 E+16 | |
| pica (computer) (1/6 in) | meter (m)<br>millimeter (mm) | 0.004 233 333<br>4.233 333 | |
| pica (printer's) | meter (m)<br>millimeter (mm) | 0.004 217 5<br>4.217 5 | |
| point (computer) (1/72 in) | meter (m)<br>millimeter (mm) | 3.527 778 E–04<br>0.352 777 8 | |
| point (printer's) | meter (m)<br>millimeter (mm) | 3.514 6 E–04<br>0.351 46 | |
| rod (16.5 US survey feet) | meter (m) | 5.029 210 | [1] |
| yard | meter (m) | **0.914 4** | |
| | ***Area*** | | |
| acre (43 560 square US survey feet) | square meter ($m^2$) | 4 046.873 | [1] |
| are | square meter ($m^2$) | **100** | |
| barn | square meter ($m^2$) | **1.0 E–28** | |
| circular mil | square meter ($m^2$)<br>square millimeter ($mm^2$) | 5.067 075 E–10<br>5.067 075 E–04 | |
| hectare | square meter ($m^2$) | **1.0 E+04** | |
| square foot ($ft^2$) | square meter ($m^2$) | **0.092 903 04** | |
| square inch ($in^2$) | square meter ($m^2$) | **6.451 6 E–04** | |
| square mile | square meter ($m^2$) | 2.589 988 E+06 | |
| square yard ($yd^2$) | square meter ($m^2$) | 0.836 127 4 | |
| | ***Volume (includes capacity)*** | | |
| acre-foot | cubic meter ($m^3$) | 1 233.5 | |
| barrel (oil, 42 US gallons) | cubic meter ($m^3$)<br>liter (L) | 0.158 987 3<br>158.987 3 | |
| board foot | See note [9] | | [9] |
| bushel (US) | cubic meter ($m^3$) | 0.035 239 07 | |
| cord | cubic meter ($m^3$) | 3.625 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

**Table A.2—Classified list of units—space and time *(continued)***

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| cubic foot ($ft^3$) | cubic meter ($m^3$) | 0.028 316 85 | |
| cubic inch ($in^3$) | cubic meter ($m^3$) | **1.638 706 4 E–05** | |
| cubic mile | cubic meter ($m^3$)<br>cubic kilometer ($km^3$) | 4.168 182 E+09<br>4.168 182 | |
| cubic yard ($yd^3$) | cubic meter ($m^3$) | 0.764 554 9 | |
| cup (US) | cubic meter ($m^3$)<br>liter (L)<br>milliliter (mL) | 2.366 E–04<br>0.236 6<br>236.6 | |
| gallon (Imperial) | cubic meter ($m^3$)<br>liter (L) | 0.004 546 09<br>4.546 09 | |
| gallon (US) 231 $in^3$) | cubic meter ($m^3$)<br>liter (L) | 0.003 785 412<br>3.785 412 | |
| liter | cubic meter ($m^3$) | **0.001** | |
| ounce (Imperial fluid) | cubic meter ($m^3$)<br>milliliter (mL) | 2.841 3 06 E–05<br>28.413 06 | |
| ounce (US fluid) | cubic meter ($m^3$)<br>milliliter (mL) | 0.029 573 53<br>29.573 53 | |
| peck (US) | cubic meter ($m^3$)<br>liter (L) | 0.008 809 8<br>8.809 8 | |
| pint (Imperial) | cubic meter ($m^3$)<br>liter (L) | **5.682 612 5 E–04**<br>**0.568 261 25** | |
| pint (US dry) | cubic meter ($m^3$)<br>liter (L) | 5.506 1 E–04<br>0.550 61 | |
| pint (US liquid) | cubic meter ($m^3$)<br>liter (L) | 4.731 76 E–04<br>0.473 176 | |
| quart (US dry) | cubic meter ($m^3$)<br>liter (L) | 0.001 101 221<br>1.101 221 | |
| quart (US liquid) | cubic meter ($m^3$)<br>liter (L) | 9.463 529 E–04<br>0.946 352 9 | |
| stere | cubic meter ($m^3$) | **1.0** | |
| tablespoon | cubic meter ($m^3$)<br>milliliter (mL) | 1.479 E–05<br>14.79 | |
| teaspoon | cubic meter ($m^3$)<br>milliliter (mL) | 4.929 E–06<br>4.929 | |
| ton, register | cubic meter ($m^3$) | 2.831 685 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

### Table A.2—Classified list of units—space and time *(continued)*

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| | ***Time*** | | |
| day (mean solar) | second (s) | **8.640 0 E+04** | |
| day (sidereal) | second (s) | 8.616 409 E+04 | |
| hour | second (s) | **3 600** | |
| hour (sidereal) | second (s) | 3 590.170 | |
| minute | second (s) | **60** | |
| minute (sidereal) | second (s) | 59.836 17 | |
| second (sidereal) | second (s) | 0.997 269 6 | |
| shake | second (s)<br>nanosecond (ns) | **1.0 E–08**<br>**10** | |
| year of 365 days | 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 | |
| | ***Velocity (includes speed)*** | | |
| 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** | |
| kilometer per hour | meter per second (m/s) | **1000/3600** = 0.277 777 8 | |
| knot (nautical mile per hour) | meter per second (m/s) | 0.514 444 4 | |
| mile per hour | meter per second (m/s)<br>kilometer per hour (km/h) | **0.447 04**<br>**1.609 344** | |
| mile per minute | meter per second (m/s) | **26.822 4** | |
| revolution per minute (rpm) | radian per second (rad/s) | **2π/60** = 0.104 719 8 | |
| | ***Acceleration*** | | |
| foot per second squared | meter per second squared ($m/s^2$) | **0.304 8** | |
| $g_n$ (standard acceleration of free fall) | meter per second squared ($m/s^2$) | **9.806 65** | |
| gal | meter per second squared ($m/s^2$) | **0.01** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

### Table A.2—Classified list of units—space and time *(continued)*

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| | ***Volume per unit time (includes flow)*** | | |
| cubic foot per minute (cfm) | cubic meter per second ($m^3/s$)<br>liter per second (L/s) | 4.719 474 E–04<br>0.471 947 4 | |
| cubic foot per second ($ft^3/s$) | cubic meter per second ($m^3/s$) | 0.028 316 85 | |
| cubic inch per minute ($in^3/min$) | cubic meter per second ($m^3/s$) | 2.731 177 E–07 | |
| cubic yard per minute ($yd^3/min$) | cubic meter per second ($m^3/s$) | 0.012 742 58 | |
| gallon (US) per day | cubic meter per second ($m^3/s$)<br>liter per second (L/s) | 4.381 264 E–08<br>4.381 264 E–05 | |
| gallon (US) per minute | cubic meter per second ($m^3/s$)<br>liter per second (L/s) | 6.309 020 E–05<br>0.063 090 20 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

### Table A.3—Classified list of units—mechanics

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| | ***Mass*** | | |
| carat (metric) | kilogram (kg)<br>gram (g) | **0.000 2**<br>**0.2** | |
| dalton | kilogram (kg) | 1.660 540 E−27 | |
| grain | kilogram (kg)<br>milligram (mg) | **6.479 891 E−05**<br>**64.798 91** | |
| hundredweight, long (112 lb) | kilogram (kg) | 50.802 35 | |
| hundredweight, short (100 lb) | kilogram (kg) | 45.359 24 | |
| ounce (avoirdupois) | kilogram (kg)<br>gram (g) | 0.028 349 52<br>28.349 52 | |
| ounce (troy or apothecary) | kilogram (kg)<br>gram (g) | 0.031 103 48<br>31.103 48 | |
| pennyweight | kilogram (kg)<br>gram (g) | 0.001 555 174<br>1.555 174 | |
| pound (avoirdupois) | kilogram (kg) | **0.453 592 37** | |
| pound (troy or apothecary) | kilogram (kg) | 0.373 241 7 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| slug | kilogram (kg) | 14.593 90 | |
| ton, assay | kilogram (kg) | 0.029 166 67 | |
| ton, long (2240 lb) | kilogram (kg) | 1 016.047 | |
| ton, metric | kilogram (kg) | **1 000** | |
| ton, short (2000 lb) | kilogram (kg) | 907.184 7 | |
| tonne | kilogram (kg) | **1 000** | |
| unified atomic mass unit (u) | kilogram (kg) | 1.660 540 E–27 | [10] |
| ***Mass per unit time (includes flow)*** | | | |
| 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 | |
| pound per hour (lb/h) | kilogram per second (kg/s) | 1.259 979 E–04 | |
| pound per minute (lb/min) | kilogram per second (kg/s) | 0.007 559 873 | |
| ton (short) per hour | kilogram per second (kg/s) | 0.251 995 8 | |
| ***Mass per unit length*** | | | |
| denier | kilogram per meter (kg/m) | 1.111 111 E–07 | |
| pound per foot (lb/ft) | kilogram per meter (kg/m) | 1.488 164 | |
| pound per inch (lb/in) | kilogram per meter (kg/m) | 17.857 97 | |
| tex | kilogram per meter (kg/m) | **1.0 E–06** | |
| ***Mass per unit area*** | | | |
| 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 | |
| pound per square foot | kilogram per square meter (kg/m$^2$) | 4.882 428 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| | ***Mass per unit volume (includes density and mass concentration)*** | | |
| grain per gallon (US) | kilogram per cubic meter ($kg/m^3$)<br>milligram per liter (mg/L) | 0.017 118 06<br>17.118 06 | |
| ounce (av) per cubic inch | kilogram per cubic meter ($kg/m^3$) | 1 729.994 | |
| ounce (av) per gallon (US) | kilogram per cubic meter ($kg/m^3$)<br>gram per liter (g/L) | 7.489 152<br>7.489 152 | |
| pound per gallon (US) | kilogram per cubic meter ($kg/m^3$)<br>kilogram per liter (kg/L) | 1.198 264 E+05<br>119.826 4 | |
| 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 | |
| ton (long) per cubic yard | kilogram per cubic meter ($kg/m^3$) | 1 328.939 | |
| ton (short) per cubic yard | kilogram per cubic meter ($kg/m^3$) | 1 186.553 | |
| | ***Force*** | | |
| dyne | newton (N) | **1.0 E−05** | |
| kilogram-force | newton (N) | **9.806 65** | |
| kilopond (kilogram-force) | newton (N) | **9.806 65** | |
| kip (1000 lbf) | newton (N)<br>kilonewton (kN) | 4 448.222<br>4.448 222 | |
| ounce-force | newton (N) | 0.278 013 9 | |
| poundal | newton (N) | 0.138 255 0 | |
| pound-force | newton (N) | 4.448 222 | |
| | ***Force per unit length*** | | |
| pound-force per foot | newton per meter (N/m) | 14.593 90 | |
| pound-force per inch | newton per meter (N/m) | 175.126 8 | |
| | ***Thrust to mass ratio*** | | |
| pound-force per pound | newton per kilogram (N/kg) | **9.806 65** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| | ***Bending moment or torque (see 3.4.4)*** | | |
| dyne centimeter | newton meter (N·m) | **1.0 E–07** | |
| foot pound-force | newton meter (N·m) | 1.355 818 | |
| inch ounce-force | newton meter (N·m) | 0.007 061 552 | |
| inch pound-force | newton meter (N·m) | 0.112 984 8 | |
| kilogram-force meter | newton meter (N·m) | **9.806 65** | |
| | ***Pressure or stress (force per unit area)*** | | |
| atmosphere, standard | pascal (Pa)<br>kilopascal (kPa) | **1.013 25 E+05**<br>**101.325** | |
| atmosphere, technical (1 kgf/cm$^2$) | pascal (Pa)<br>kilopascal (kPa) | **9.806 65 E+04**<br>**98.066 5** | |
| bar | pascal (Pa)<br>kilopascal (kPa) | **1.0 E+05**<br>**100** | |
| centimeter of water | pascal (Pa) | **98.066 5** | [2] |
| dyne per square centimeter | pascal (Pa) | **0.1** | |
| foot of water | pascal (Pa)<br>kilopascal (kPa) | 2 989.07<br>2.989 07 | [2] |
| inch of mercury | pascal (Pa)<br>kilopascal (kPa) | 3 386.39<br>3.386 39 | [2] |
| inch of water | pascal (Pa) | 249.089 | [2] |
| kilogram-force per square centimeter | pascal (Pa)<br>kilopascal (kPa) | **9.806 65 E+04**<br>**98.066 5** | |
| kilogram-force per square meter | pascal (Pa) | **9.806 65** | |
| kip per square inch (ksi) | pascal (Pa)<br>kilopascal (kPa) | 6.894 757 E+06<br>6 894.757 | |
| millibar | pascal (Pa)<br>kilopascal (kPa) | **100**<br>**0.1** | |
| millimeter of mercury | pascal (Pa) | 133.322 | [2] |
| poundal per square foot | pascal (Pa) | 1.488 164 | |
| pound-force per square foot (psf) | pascal (Pa) | 47.880 26 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| pound-force per square inch (psi) | pascal (Pa)<br>kilopascal (kPa) | 6 894.757<br>6.894 757 | |
| torr | pascal (Pa) | 133.322 | |
| ***Viscosity*** | | | |
| centipoise | pascal second (Pa·s) | **0.001** | |
| centistokes | square meter per second ($m^2$/s) | **1.0 E–06** | |
| poise | pascal second (Pa·s) | **0.1** | |
| pound-force second per square foot | pascal second (Pa·s) | 47.880 26 | |
| pound-force second per square inch | pascal second (Pa·s) | 6 894.757 | |
| pound per foot hour | pascal second (Pa·s) | 4.133 789 E–04 | |
| pound per foot second | pascal second (Pa·s) | 1.488 164 | |
| rhe | 1 per pascal second [1/(Pa·s)] | **10** | |
| square foot per hour | square meter per second ($m^2$/s) | **2.580 64 E–05** | |
| stokes | square meter per second ($m^2$/s) | **1.0 E–04** | |
| ***Energy and work*** | | | |
| British thermal unit (Btu) (International Table) | joule (J) | 1 055.056 | [3] |
| British thermal unit (Btu) (thermochemical) | joule (J) | 1 054.350 | [3] |
| calorie (thermochemical) | joule (J) | **4.184** | [3] |
| calorie, nutrition (kilocalorie) | joule (J) | **4 184** | [3] |
| electronvolt | joule (J) | 1.602 19 E–19 | [10] |
| erg | joule (J) | **1.0 E–07** | |
| foot poundal | joule (J) | 0.042 140 11 | |
| foot pound-force | joule (J) | 1.355 818 | |
| kilocalorie (thermochemical) | joule (J) | **4 184** | [3] |
| kilowatthour | joule (J)<br>megajoule (MJ) | **3.6 E+06**<br>**3.6** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| quad | joule (J) | 1.055 E+18 | |
| therm (EEC) | joule (J) | **1.055 06 E+08** | [4] |
| therm (US) | joule (J) | **1.054 804 E+08** | [4] |
| ton (from energy equivalent of one ton of TNT) ($10^6$ kcal) | joule (J) | **4.184 E+09** | |
| ton of oil equivalent ($10^7$ kcal) | joule (J) | **4.184 E+10** | |
| watthour | joule (J) | **3 600** | |
| wattsecond | joule (J) | **1.0** | |
| | ***Energy per unit area time*** | | |
| erg per square centimeter second | watt per square meter (W/m$^2$) | **0.001** | |
| watt per square centimeter | watt per square meter (W/m$^2$) | **1.0 E+04** | |
| watt per square inch | watt per square meter (W/m$^2$) | 1 550.003 | |
| | ***Power*** | | |
| erg per second | watt (W) | **1.0 E–07** | |
| foot pound-force per hour | watt (W) | 3.766 161 E–04 | |
| foot pound-force per minute | watt (W) | 0.022 596 97 | |
| foot pound-force per second | watt (W) | 1.355 818 | |
| horsepower (550 ft·lbf/s) | watt (W) | 745.699 9 | |
| horsepower (boiler) | watt (W) | 9 809.50 | |
| horsepower (electric) | watt (W) | **746** | |
| horsepower (metric) | watt (W) | 735.499 | |
| horsepower (water) | watt (W) | 746.043 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

**Table A.4—Classified list of units—heat**

| To convert from | To | Use | |
|---|---|---|---|
| | ***Temperature*** | | |
| degree Celsius (°C) | kelvin (K) | $T_K = t_{°C} + \mathbf{273.15}$ | |
| degree centigrade | degree Celsius (°C) | $t_{°C} \approx t_{centigrade}$ | |
| degree Fahrenheit (°F) | degree Celsius (°C) | $t_{°C} = (t_{°F} - \mathbf{32})/\mathbf{1.8}$ | |
| degree Fahrenheit (°F) | kelvin (K) | $T_K = (t_{°F} + \mathbf{459.67})/\mathbf{1.8}$ | |
| degree Rankine (°R) | kelvin (K) | $T_K = T_{°R}/\mathbf{1.8}$ | |
| kelvin (K) | degree Celsius (°C) | $t_{°C} = T_K - \mathbf{273.15}$ | |
| **To convert from** | **To** | **Multiply by**[1] | **Note**[2] |
| | ***Temperature interval*** | | |
| degree Celsius (°C) | kelvin (K) | **1.0** | |
| degree centigrade | degree Celsius (°C) | 1.0 | |
| degree Fahrenheit (°F) | kelvin (K) | 0.555 555 6 | |
| degree Fahrenheit (°F) | degree Celsius (°C) | 0.555 555 6 | |
| degree Rankine (°R) | kelvin (K) | 0.555 555 6 | |
| | ***Thermal energy*** | | |
| British thermal unit (Btu) (International Table) | joule (J) | 1 055.056 | [3] |
| calorie (thermochemical) | joule (J) | **4.184** | [3] |
| calorie, nutrition | joule (J) | **4 184** | [3] |
| kilocalorie | joule (J) | **4 184** | [3] |
| therm (EEC) | joule (J) | **1.055 06 E+08** | [4] |
| therm (US) | joule (J) | **1.054 804 E+08** | [4] |
| | ***Heat flow rate*** | | |
| Btu per hour | watt (W) | 0.293 071 1 | [3] |
| Btu per second | watt (W) | 1 055.056 | [3] |
| calorie per minute | watt (W) | 0.069 733 33 | [3] |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| calorie per second | watt (W) | **4.184** | [3] |
| ton of refrigeration (12 000 Btu/h) | watt (W) | 3 517 | [3] |
| | ***Density of heat flow rate*** | | |
| Btu per hour square foot | watt per square meter ($W/m^2$) | 3.154 591 | [3] |
| Btu per second square foot | watt per square meter ($W/m^2$) | 1.135 653 E+04 | [3] |
| calorie per square centimeter minute | watt per square meter ($W/m^2$) | 697.333 3 | [3] |
| calorie per square centimeter second | watt per square meter ($W/m^2$) | **4.184 E+04** | [3] |
| | ***Thermal conductivity*** | | |
| Btu foot per hour square foot degree Fahrenheit | watt per meter kelvin [W/(m·K)] | 1.730 735 | |
| Btu inch per hour square foot degree Fahrenheit | watt per meter kelvin [W/(m·K)] | 0.144 227 9 | |
| Btu inch per second square foot degree Fahrenheit | watt per meter kelvin [W/(m·K)] | 519.220 4 | |
| calorie per centimeter second degree Celcius | watt per meter kelvin [W/(m·K)] | **418.4** | |
| | ***Coefficient of heat transfer*** | | |
| Btu per hour square foot degree Fahrenheit | watt per square meter kelvin [$W/(m^2 \cdot K)$] | 5.678 263 | |
| Btu per second square foot degree Fahrenheit | watt per square meter kelvin [$W/(m^2 \cdot K)$] | 2.044 175 E+04 | |
| | ***Thermal insulance*** | | |
| clo | kelvin square meter per watt ($K \cdot m^2/W$) | 0.155 | |
| degree Fahrenheit hour square foot per Btu | kelvin square meter per watt ($K \cdot m^2/W$) | 0.176 110 2 | |
| | ***Thermal resistivity*** | | |
| degree Fahrenheit hour square foot per Btu inch | kelvin meter per watt (K·m/W) | 6.933 472 | |
| | ***Thermal resistance*** | | |
| degree Fahrenheit hour per Btu | kelvin per watt (K/W) | 1.895 634 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| | ***Thermal diffusivity*** | | |
| square foot per hour | square meter per second ($m^2/s$) | **2.580 64 E−05** | |
| | ***Heat capacity and entropy*** | | |
| Btu per degree Fahrenheit | joule per kelvin (J/K) | 1899.101 | |
| Btu per degree Rankine | joule per kelvin (J/K) | 1899.101 | |
| | ***Specific heat capacity*** | | |
| Btu per pound degree Fahrenheit | joule per kilogram kelvin [J/(kg·K)] | **4 186.8** | |
| Btu per pound degree Rankine | joule per kilogram kelvin [J/(kg·K)] | **4 186.8** | |
| calorie per gram degree Celsius | joule per kilogram kelvin [J/(kg·K)] | **4 184** | |
| | ***Density of heat*** | | |
| Btu per square foot | joule per square meter ($J/m^2$) | 1.135 653 E+04 | |
| calorie per square centimeter | joule per square meter ($J/m^2$) | **4.184 E+04** | |
| | ***Internal energy*** | | |
| Btu per cubic foot | joule per cubic meter ($J/m^3$) | 3.725 895 E+04 | |
| Btu per pound | joule per kilogram (J/kg) | **2 326** | |
| calorie per gram | joule per kilogram (J/kg) | **4 184** | |
| | ***Fuel consumption*** | | |
| gallon (US) per horsepower hour | cubic meter per joule ($m^3/J$) | 1. 410 089 E–09 | |
| mile per gallon (US) (mpg) | meter per cubic meter ($m/m^3$)<br>kilometer per liter (km/L)<br>liter per 100 kilometers (L/100 km) | 4.251 437 E+05<br>0.425 143 7<br>divide 235.215 by the number of miles per gallon | [5] |
| pound per horsepower hour | kilogram per joule (kg/J) | 1.689 659 E–07 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

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

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| ampere hour | coulomb (C) | **3 600** | |
| biot | ampere (A) | **10** | |
| faraday (based on carbon 12) | coulomb (C) | 9.648 531 E+04 | |
| franklin | coulomb (C) | 3.335 641 E–10 | |
| gamma | tesla (T) | **1.0 E–09** | |
| gauss | tesla (T) | **1.0 E–04** | |
| gilbert | ampere (A) | 0.795 774 7 | |
| kilowatthour | joule (J)<br>megajoule (MJ) | **3.6 E+06**<br>**3.6** | |
| maxwell | weber (Wb) | **1.0 E–08** | |
| mho | siemens (S) | **1.0** | |
| oersted | ampere per meter (A/m) | 79.577 47 | |
| ohm centimeter | ohm meter (Ω·m) | **0.01** | |
| ohm circular-mil per foot | ohm meter (Ω·m) | 1.662 426 E–09 | |
| ohm circular-mil per foot | ohm square millimeter per meter (Ω·mm$^2$/m) | 0.001 662 426 | |
| unit pole | weber (Wb) | 1.256 637 E–07 | |
| ***Electromagnetic CGS units*** | | | |
| 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 (Ω) | **1.0 E–09** | |
| abvolt | volt (V) | **1.0 E–08** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

### Table A.5—Classified list of units—electricity and magnetism *(continued)*

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| | ***Electrostatic CGS units*** | | |
| 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 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

### Table A.6—Classified list of units—radiology

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| curie | becquerel (Bq) | **3.7 E+10** | |
| rad (absorbed dose) | gray (Gy) | **0.01** | |
| rem (dose equivalent) | sievert (Sv) | **0.01** | |
| roentgen | coulomb per kilogram (C/kg) | **2.58 E–04** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and, therefore, all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

### Table A.7—Classified list of units—light

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| candle, candlepower | candela (cd) | **1.0** | |
| candela per square inch | candela per square meter ($cd/m^2$) | 1 550.003 | |
| footcandle | lux (lx) | 10.763 91 | |
| footlambert | candela per square meter ($cd/m^2$) | 3.426 259 | |

[1] A multiplier in bold type indicates that the conversion factor is exact and that all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

### Table A.7—Classified list of units—light *(continued)*

| To convert from | To | Multiply by[1] | Note[2] |
|---|---|---|---|
| jansky (Jy) | watt per square meter hertz [$W/(m^2 \cdot Hz)$] | **1.0 E−26** | |
| lambert | candela per square meter ($cd/m^2$) | 3 183.099 | |
| lumen per square foot | lumen per square meter ($lm/m^2$) | 10.763 91 | |
| phot | lumen per square meter ($lm/m^2$) | **1.0 E+04** | |
| stilb | candela per square meter ($cd/m^2$) | **1.0 E+04** | |

[1] A multiplier in bold type indicates that the conversion factor is exact and that all subsequent digits are zero.
[2] Numbers in the Note column refer to A.4.2.

# Annex B

(informative)

# Rules for conversion and rounding

## B.1 Terminology

A clear understanding of the terms used in this standard will help ensure reliable conversion and rounding practices. These terms and their definitions are as follows:

**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 feature:** An individual characteristic of a part, such as screw-thread, taper, or slot.

**B.1.6 figure (numerical):** An arithmetic value expressed by one or more digits.

**B.1.7 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.1.8 nominal value:** A value assigned for convenient designation; existing in name only.

**B.1.9 precision:** The degree of mutual agreement between individual measurements, namely their repeatability and reproducibility. (*Compare:* accuracy.)

**B.1.10 significant digit:** Any digit in a number that is necessary to define a numerical value. (See Clause B.3.)

**B.1.11 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 Clause 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 Clause 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 ft × 0.3048 m/ft) + (2.5625 in × 0.0254 m/in) = 0.979 487 5 m, which rounds to 0.979 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 US 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. 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: | $113.2 \times 1.43 = 161.876$, 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.

Many techniques are used to determine the proper number of significant digits in the converted values. Two methods of rounding values are described in this clause, one for general use and the other for conversion of dimensions involving mechanical interchangeability.

### 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 Clause 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 lbf/in$^2$ (psi) ± 15 lbf/in$^2$ (psi). Since one-tenth of the tolerance is 3 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 Clause 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 4 in wide” requires a width of at least 101.6 mm, or at least 102 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. It includes a unit of force (newton). SI is a coherent system with seven base units for which names, symbols, and precise definitions have been established. Units can be derived for any quantity that is defined in terms of the base units; have symbols assigned to each; and, in some cases, are given names, as for example, the newton (N).

A great advantage of SI is that there is one and only one 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 2). 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).

Another advantage of SI is its retention of 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 talking.

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 Selection of units

Whatever the system of units, whether it be coherent or noncoherent, particular samples of some physical quantities must be arbitrarily selected as units of those quantities. The remaining units are defined by appropriate experiments related to the theoretical interrelations of all the quantities. For convenience of analysis, certain units are by convention regarded as dimensionally independent; these units are called base units, and all other units (derived units) can be expressed algebraically in terms of the base units. In the SI, the unit of mass, the kilogram, is defined as the mass of a particular “prototype kilogram” preserved by the International Bureau of Weights and Measures. It is the only SI base unit still defined in terms of a material artifact.

Various other units are associated with SI but are not a part thereof. They are related to units of the system by powers of 10 and are used in specialized technologies and circumstances. Examples of such units are the bar, a unit of pressure, approximately equivalent to 1 atmosphere and exactly equal to 100 kPa. It is employed extensively by meteorologists. Another such unit is the gal, exactly equal to an acceleration of 0.01 $m/s^2$. It is used in geodetic work. These, however, are not coherent units; that is to say, equations involving these units and SI units together cannot be written without a factor of proportionality (even though the factor of proportionality is a simple power of 10).

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 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 $2 \times 10^{-7}$ 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 $540 \times 10^{12}$ 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

| | Physical quantity | 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<br><br>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 $t = T - T_o$, where $T$ is the thermodynamic temperature and $T_o = 273.15$ 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, quantity of electricity | 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. |

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

| Physical quantity | Unit and definition |
|---|---|
| (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. |
| (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) 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. |
| (18) 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. |
| (19) 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. |
| (20) Power | The *watt* is the power that represents a rate of energy transfer of one joule per second. |
| (21) 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 Comments on angle

The dimensional analysis of quantities is to some extent a matter of taste. For example, force, rather than mass, is often chosen as a convenient base quantity in performing dimensional analyses.

Dimensional analysis that uses only the seven SI base quantities does not distinguish between energy and torque (i.e., they have the same dimension in SI), even though the two quantities are of a different nature. More precisely, they are not *mutually comparable quantities*; that is, they are not *quantities of the same kind*. For example, it is meaningless to ask if a particular energy is larger or smaller than a particular torque. Many such dimensional ambiguities can be clarified if the quantity plane angle (or solid angle) is treated as a base quantity with its own base unit of measurement. The General Conference on Weights and Measures (CGPM) and the International Standards Organization (ISO) Technical Committee 12 consider the unit of angle as only a number (following Maxwell's approach), but allow the use of the name "radian" (rad) for the unit of angle when appropriate and convenient.

Because this standard follows SI as defined by the CGPM, it follows the convention that the coherent (SI) unit of angle is the number 1. Treating plane angle (and solid angle) as a base quantity is useful, but it is not

SI. In a system in which the radian is taken as a base unit, torque may be expressed in the unit joule per radian. For further details, see [B32] and the references cited therein.

## C.6 Comment on spelling

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

## C.7 Comments on mass, force, and weight

### C.7.1 Distinction between units for mass and force

Mass units, such as kilogram, pound, and ounce, have often been used for units of both mass and 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.7.2 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.7.3 Load

The term “load” in mechanics means either mass, force, or pressure, depending on its use. A load that produces a vertical downward force because of the influence of gravity acting on a mass may be expressed in mass units, e.g., kilograms. A load that produces a force from anything other than the influence of gravity is expressed in force units, i.e., newtons, although the pascal is used in some cases. For example, a wind, snow, or roof load may be a pressure and may be expressed in newtons per square meter ($N/m^2$), that is, pascals (Pa). Floor loading in a building, however, may properly be expressed in mass units, e.g. in kilograms or kilograms per square meter.

### C.7.4 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 the French Academy of Sciences to 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 United States, 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 May 20, 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 United States 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 United States, 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 (see Table 2). 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 October 1995, 48 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, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Korea (Democratic People's Republic of), Korea (Republic of), Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Portugal, Romania, Russian Federation, Singapore, Slovak Republic, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, the United States of America, Uruguay, Venezuela.

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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[4]This publication is available from Bureau International des Poids et Mesures, Pavillon de Breteuil, F-92310, Sèvres, France.

[5]IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[6]ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

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