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American National Standard for Metric Practice

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Approved 8 December 2010

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Abstract: Guidance for the use of the modern metric system is given. Known as the International System of Units (abbreviated SI), the system is the basis for worldwide standardization of measurement units. Information is included on SI, a list of units recognized for use with SI, and a list of conversion factors, together with general guidance on proper style and usage.

Keywords: conversion factors, International System, International System of Units, metric practice, metric system, rounding, SI, SI 10, Système International d'Unités

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Introduction

This introduction is not part of IEEE/ASTM SI 10-2011, American National Standard for Metric Practice.

This document, which supersedes IEEE/ASTM SI 10-2002, is the primary American National Standard for use of the International System of Units (SI). The first version of this standard that was published jointly by the IEEE and ASTM appeared in 1976. The sponsoring societies welcome comments and suggestions from interested individuals and organizations.

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

SI is defined in the document *Le Système International d'Unités,* published in French, with an English translation, by the International Bureau of Weights and Measures (BIPM). The BIPM was set up by the Convention du Mètre, signed in 1875 (see Annex D). *Le Système International d'Unités,* known informally as the "BIPM SI Brochure," is revised from time to time in accordance with the decisions of the General Conference on Weights and Measures (CGPM) and other international organizations. A U.S. version is published by NIST [B22].[a]

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

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Participants

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1. Overview

1.1 Scope

This document is the primary American National Standard on application of the metric system. It emphasizes use of the International System of Units (SI), which is the modern, internationally accepted metric system. It 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. It also lists older "metric" units that shall no longer be used. The word "primary" implies that other metric standards in the United States should be consistent with this document.

1.2 Introduction

Any measurable physical quantity can be represented in the SI with the aid of just seven "base units"—the units for the quantities length, mass, time, electric current, temperature, amount of substance, and luminous intensity—or by combinations (called "derived units") of these seven. For example, the unit of speed can be expressed by the unit of length divided by the unit of time. This standard shows first the two classes of units (base and derived) that make up the SI, together with the standard symbols that may be used to represent them. Prefixes that allow the formation of decimal multiples and submultiples are explained. Notes on the proper use of the SI units and symbols in many applications follow.

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

2. SI units and symbols

2.1 Classes of units

2.1.1 Base units

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

Table 1—SI base units

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

2.1.2 Derived units

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

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

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

For convenience, certain derived units have been given special names and symbols. Those that are approved by the General Conference on Weights and Measures (abbreviated CGPM from its name in French; see Annex D), and are therefore formally part of the SI, are listed in Table 3.[1] Definitions are provided in C.4.

[1]Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

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Table 3—SI derived units with special names and symbols

Derived quantity	SI derived unit			
	Unit name	Unit symbol	Expressed in terms of other SI units	Expressed in terms of SI base units
angle, plane	radian	rad		$m \cdot m^{-1} = 1$ [See NOTE]
angle, solid	steradian	sr		$m^2 \cdot m^{-2} = 1$ [See NOTE]
frequency (of a periodic phenomenon)	hertz	Hz		s^{-1}
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C		$s \cdot A$
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2; $N/(A \cdot m)$	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
luminous flux	lumen	lm	$cd \cdot sr$	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	lux	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
activity (referred to a radionuclide)	becquerel	Bq		s^{-1}
absorbed dose, specific energy imparted, kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent, organ equivalent dose	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
catalytic activity	katal	kat		$s^{-1} \cdot mol$
NOTE—If the SI units are considered as a mathematical group, group theory requires that the number 1 be included with the base units. The CGPM has not yet adopted this position.				

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

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

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

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Derived quantity	SI derived unit		
	Unit name	Unit symbol	Expressed in terms of SI base units
surface tension	newton per meter	N/m	$kg \cdot s^{-2}$
surface tension	joule per square meter	J/m^2	$kg \cdot s^{-2}$
thermal conductivity	watt per meter kelvin	$W/(m \cdot K)$	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
viscosity, dynamic	pascal second	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
viscosity, kinematic	square meter per second	m^2/s	$m^2 \cdot s^{-1}$

2.1.3 Coherence

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

2.2 SI prefixes

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

2.2.1 Unit of mass

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

Table 5—SI prefixes

Name	Symbol	Multiplication factor
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	$10^{3} = 1000$
hecto	h	$10^{2} = 100$
deka	da	$10^{1} = 10$
deci	d	$10^{-1} = 0.1$
centi	c	$10^{-2} = 0.01$

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Name	Symbol	Multiplication factor
milli	m	$10^{-3} = 0.001$
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

2.2.2 Limited character sets

When the metric system developed in the 19th century, all educated persons were familiar with the Greek alphabet, and the Greek letters lowercase mu (for micro) and uppercase omega (for ohm) were standardized and have been included in the official SI Brochure. This presents a problem now with limited character sets, especially in embedded and applied computer operating systems used in manufacturing and labware. IEEE Std 260.1™-2004 [B8][2] addresses this problem and prescribes lowercase u as a substitute prefix symbol for micro and Ohm (note the uppercase O) as a substitute unit symbol for ohm when Greek letters are not available. It also gives recommendations where only uppercase or only lowercase letters are available.

3. Use of the SI

3.1 General

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

3.2 Application of SI prefixes

3.2.1 General

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

[2]The numbers in brackets correspond to those of the bibliography in Annex E.

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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 convenient, for example, cubic decimeter, square hectometer, or 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, clothing sizes, household products, and other everyday purposes for which millimeters are inconveniently precise.

3.2.3 Compound prefixes

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

1.3 nm, *not* 1.3 mμm

2.4 pF, *not* 2.4 μμF

3.2.4 Powers of units

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

Examples:

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

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

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

3.2.5 Prefixes defined as powers of two

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

The International Electrotechnical Commission (IEC) and the IEEE have adopted standard prefixes for binary multiples. These include kibi (Ki) for 2^{10}, mebi (Mi) for 2^{20}, and gibi (Gi) for 2^{30}. See NIST Special Publication 811 [B23] and NIST Technical Note 1265 [B25].

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3.3 Other units

3.3.1 Units from other systems

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

Table 6—Units in use with SI

Quantity	Unit name	Unit symbol	Exact value in SI units
time	minute	min	min = 60 s
	hour	h	h = 60 min = 3600 s
	day	d	d = 24 h = 86 400 s
	month	mo	
	year	a	
plane angle	degree[a]	°	1° = (π /180) rad
	minute[a]	′	1′ = (1/60)° = (π /10 800) rad
	second[a]	″	1″ = (1/60)′ = (π /648 000) rad
	revolution, turn	r	r = 2π rad
distance	nautical mile	nmi	nmi = 1852 m
speed	knot	kn	kn = nmi/h
area	hectare	ha	ha = 1 hm^2 = 10^4 m^2
volume	liter[b]	L	L = 1 dm^3 = 10^{-3} m^3
mass	metric ton	t	t = 1 Mg = 10^3 kg

[a]Decimal degrees should be used for division of degrees, except for fields such as astronomy and cartography.
[b] See 3.3.2.4.

Table 7—Units whose values are obtained experimentally

Quantity	Unit name	Unit symbol	Value in SI units[a]
energy	electronvolt[b]	eV	eV = 1.602 176 487(40) × 10^{-19} J
mass	unified atomic mass unit[c]	u	u = 1.660 538 782(83) × 10^{-27} kg

[a]The numerical values are taken from Mohr, Taylor, and Newell [B26]. The values are given with their combined standard uncertainties, which apply to the last two digits, shown in parentheses.
[b]The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum.
[c]The unified atomic mass unit is equal to 1/12 of the mass of an unbound atom of the nuclide ^{12}C at rest and in its ground state. The special name dalton (Da) is also used for the atomic mass unit.

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3.3.2 Units in use with SI

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

3.3.2.1 Time

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

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 of plane angle is permissible when the radian is not convenient.

3.3.2.3 Area

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

3.3.2.4 Volume

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

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

3.3.2.5 Mass

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

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

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3.3.2.6 Units whose values are obtained experimentally

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

3.3.3 Units and names that are not to be used

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

3.3.3.1 Pressure and stress

The SI unit of pressure and stress is the pascal (newton per square meter), and with appropriate SI prefixes it should be used in all applications (see also 3.4.7). The kilopascal is useful in many practical applications—normal atmospheric pressure is approximately 100 kPa, and automobile manufacturers are specifying tire pressure in kPa. Do not use old metric units for pressure and stress such as kilogram-force per square centimeter (kgf/cm^2) or other non-SI units, such as torr, millimeter of mercury, or meter of water for pressure.

3.3.3.2 Centimeter-gram-second (CGS) units

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

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

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

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

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

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

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

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