Guide for Metric Practice

Internationally recognized conventions have been established for standard usage of SI units.

Robert A. Nelson

The modernized metric system is known as the *Système International d'Unités* (International System of Units), with the international abbreviation SI. It is founded on seven base units, listed in table 1, that by convention are regarded as dimensionally independent. All other units are derived units, formed coherently by multiplying and dividing units within the system without numerical factors. Examples of derived units, including some with special names, are listed in table 2. The expression of multiples and submultiples of SI units is facilitated through the use of the prefixes listed in table 3.

SI obtains its international authority from the Meter Convention, signed in Paris by the delegates of 17 countries, including the United States, on 20 May 1875, and amended in 1921. The treaty established the *Conférence Générale des Poids et Mesures* (General Conference on Weights and Measures) as the formal diplomatic body responsible for ratification of new proposals related to metric units. The scientific decisions are made by the *Comité International des Poids et Mesures* (International Committee for Weights and Measures). It is assisted by the advice of 10 Consultative Committees specializing in particular areas of metrology. The activities of the national standards laboratories are coordinated by the *Bureau International des Poids et Mesures* (International Bureau of Weights and Measures), which has its headquarters in Sèvres, France, and operates under the supervision of the CIPM. The SI was established by the 11th CGPM in 1960, when the metric unit definitions, symbols, and terminology were extensively revised and simplified.[1] Today there are 51 member states of the Meter Convention and 16 associates of the General Conference.

The BIPM, with the guidance of the Consultative Committee for Units and approval of the CIPM, periodically publishes a document[2] that summarizes the historical decisions of the CGPM and the CIPM and gives some conventions for metric practice. In addition, Technical Committee 12 of the International Organization for Standardization has prepared recommendations concerning the practical use of the SI.[3] Some other recommendations have been given by the Commission for Symbols, Units, Nomenclature, Atomic Masses and Fundamental Constants of the International Union of Pure and Applied Physics.[4] The National Institute of Standards and Technology (NIST) has published a practical guide for the use of the SI.[5] The Institute of Electrical and Electronics Engineers (IEEE) and the American Society for Testing and Materials (ASTM) have jointly prepared a metric practice manual[6] that has been recognized by the American National Standards Institute (ANSI). The Secretary of Commerce, through NIST, has also issued recommendations for US metric practice,[7] as provided under the Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988. Additional information is available on the Internet at the BIPM[8] and NIST[9] Web sites.

Robert Nelson is president of Satellite Engineering Research Corporation, a consulting firm in Bethesda, Maryland.

Table 1. SI base units

Quantity	Unit	
	Name	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

Table 2. Examples of SI derived units

Quantity	Unit		
	Special name	Symbol	Equivalent
plane angle	radian	rad	m/m=1
solid angle	steradian	sr	m^2/m^2=1
speed, velocity			m/s
acceleration			m/s^2
angular velocity			rad/s
angular acceleration			rad/s^2
frequency	hertz	Hz	s^{-1}
force	newton	N	$kg·m/s^2$
pressure, stress	pascal	Pa	N/m^2
work, energy, heat	joule	J	N·m, $kg·m^2/s^2$
impulse, momentum			N·s, kg·m/s
power	watt	W	J/s
electric charge	coulomb	C	A·s
electric potential, emf	volt	V	J/C, W/A
resistance	ohm	W	V/A
conductance	siemens	S	A/V, W^{-1}
magnetic flux	weber	Wb	V·s
inductance	henry	H	Wb/A
capacitance	farad	F	C/V
electric field strength			V/m, N/C
magnetic flux density	tesla	T	Wb/m^2, N/(A·m)
electric displacement			C/m^2
magnetic field strength			A/m
Celsius temperature	degree Celsius	°C	K
luminous flux	lumen	lm	cd·sr
illuminance	lux	lx	lm/m^2
radioactivity	becquerel	Bq	s^{-1}
catalytic activity	katal	kat	mol/s

Style conventions

Letter symbols include quantity symbols and unit symbols. Symbols for physical quantities are set in italic (sloping) type, while symbols for units are set in roman (upright) type (for example, F = 15 N).

A unit symbol is a universal mathematical entity. It is not an abbreviation and is not followed by a period (for example, the symbol for second is s, not sec or s.). Symbols for units with proper names have the first letter capitalized—otherwise unit symbols are lower case—but the unit names themselves are not capitalized (for example, tesla, T; meter, m). In contrast to unit symbols, the spelling and grammar for unit names are specific to a given language and are not part of the SI (for example, the spellings kilogram and ampere are used in English, while kilogramme and ampère are used in French, but kg and A are the universal SI symbols). Plurals of unit names are formed according to the usual rules of grammar (for example, kilopascals, henries) with the exceptions lux, hertz, and siemens, which are irregular.[5] Unit symbols are not pluralized (for example, 3 kg, not 3 kgs).

Table 3. SI prefixes

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

Table 4. Units accepted for use with the SI

Quantity	Unit		
	Name	Symbol	Definition
time	minute	min	1 min=60 s
	hour	h	1 h=60 min=3600 s
	day	d	1 d=24 h=86 400 s
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	1 L=1 dm³=10⁻³ m³
mass	metric ton	t	1 t=1000 kg
attenuation, level	neper	Np	1 Np=1
	bel	B	1 B=½ ln 10 Np

The word "degree" and its symbol, °, are omitted from the unit of thermodynamic temperature T (that is, one uses kelvin or K, not degree Kelvin or °K). However, they are retained in the unit of Celsius temperature t, defined as $t \equiv T - T_0$, where $T_0 = 273.15$ K exactly (that is, one uses degree Celsius or °C).

Symbols for prefixes representing 10^6 or greater are capitalized; all others are lower case. There is no space between the prefix and the unit. Compound prefixes are to be avoided (for example, pF, not $\mu\mu$F). An exponent applies to the whole unit including its prefix (for example, cm³ = 10^{-6} m³). When a unit multiple or submultiple is written out in full, the prefix should be written in full, beginning with a lowercase letter (for example, megahertz, not Megahertz or Mhertz). The kilogram is the only base unit whose name, for historical reasons, contains a prefix; names of multiples and submultiples of the kilogram and their symbols are formed by attaching prefixes to the word "gram" and the symbol "g."

Multiplication of units is indicated by inserting a raised dot or by leaving a space between the units (for example, N·m or N m). Division may be indicated by the use of the solidus, a horizontal fraction bar, or a negative exponent (for example, m/s, or m·s⁻¹), but repeated use of the solidus is not permitted (for example, m/s², not m/s/s). To avoid possible misinterpretation when more than one unit appears in the denominator, the preferred practice is to use parentheses or negative exponents (for example, W/(m²·K⁴) or W·m⁻²·K⁻⁴). The unit expression may include a prefixed unit in the numerator or denominator (for example, mN/m, W/cm²).

Unit names should not be mixed with symbols for mathematical operations. (For example, one should write "meter per second" but not "meter/second" or "meter second⁻¹.") When spelling out the product of two units, a space is recommended (although a hyphen is permissible), but one should never use a centered dot. (Write, for example, "newton meter" or "newton-meter," but not "newton·meter.")

Three-digit groups in numbers with more than four digits are separated by thin spaces instead of commas (for example, 299 792 458, not 299,792,458) to avoid confusion with the decimal marker in European literature. This spacing convention is also used to the right of the decimal marker. The numerical value and unit symbol must be separated by a space, even when used as an adjective (for example, 35 mm, not 35mm or 35-mm). A zero should be placed in front of the decimal marker in decimal fractions (for example, 0.3 J, not .3 J).

Table 5. Non-SI units accepted for use with the SI whose values in SI units are obtained experimentally

Quantity	Unit		
	Name	Symbol	Value
energy	electron volt*	eV	1.602 176 462(63)×10⁻¹⁹ J
mass	unified atomic mass unit*	u	1.660 538 73(13)×10⁻²⁷ kg
distance	astronomical unit**	ua	1.495 978 706 91(6)×10¹¹ m

* P. J. Mohr, B. N. Taylor, *J. Phys. Chem. Ref. Data* **28**, 1713 (1999); *Rev. Mod. Phys.* **72**, 351 (2000).
** D. D. McCarthy, G. Petit, eds., *IERS Conventions (2003)*, IERS Technical Note 32, International Earth Rotation Service (November 2003), available at http://www.iers.org.

Non-SI units

An important function of the SI is to discourage the proliferation of unnecessary units. However, there are three categories of units outside the SI that are recognized. "Units accepted for use with the SI" are listed in Table 4. As exceptions to the rules, the symbols °, ′ and ″ for plane angle are not preceded by a space, and the symbol for liter, L, is capitalized to avoid confusion with the number 1. "Non-SI units accepted for use with the SI whose values in SI units are obtained experimentally" are given in Table 5. The third category, "other non-SI units currently accepted for use with the SI," consists of the nautical mile, knot, are, hectare, bar, angstrom, and barn.

References

1. For a history of the metric system and SI units, see R. A. Nelson, *Phys. Teach.* **19**, 596 (1981); R. A. Nelson, *Via Satellite* **15**(2), 90 (2000).
2. Bureau International des Poids et Mesures, *Le Système International d'Unités (SI)*, 7th ed., BIPM, Sèvres, France (1998); US ed.: *The International System of Units (SI)*, B. N. Taylor, ed., Natl. Inst. Stand. Technol. Spec. Pub. 330, US Govt. Printing Office, Washington, DC (2001).
3. International Organization for Standardization, *Quantities and Units*, ISO Standards Handbook, 3rd ed., ISO, Geneva (1993). This is a compilation of individual standards ISO 31-0 to 31-13 and ISO 1000, available from Am. Natl. Stand. Inst., New York.
4. E.R. Cohen, P. Giacomo, eds., *Physica* **146A**, 1 (1987). Reprinted as *Symbols, Units, Nomenclature and Fundamental Constants in Physics* (1987 revision), document IUPAP-25 (SUNAMCO 87-1).
5. B. N. Taylor, *Guide for the Use of the International System of Units*, Natl. Inst. Stand. Technol. Spec. Pub. 811, US Govt. Printing Office, Washington, DC (1995).
6. IEEE Standards Coordinating Committee 14 on Quantities, Units, and Letter Symbols and ASTM Committee E-43 on SI Practice, *American National Standard for Use of the International System of Units (SI): The Modern Metric System*, IEEE/ASTM SI 10-2002, Institute of Electrical and Electronics Engineers, New York, and American Society for Testing and Materials, West Conshohocken, PA (2002).
7. B. N. Taylor, ed., *Interpretation of the SI for the United States and Federal Government Metric Conversion Policy*, Natl. Inst. Stand. Technol. Spec. Pub. 814, US Govt. Printing Office, Washington, DC (1998); *Federal Register* **63**(144), 40334 (28 July 1998).
8. http://www.bipm.org
9. http://physics.nist.gov/cuu ■