NBS GUIDELINES FOR USE OF THE METRIC SYSTEM

LC1056
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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

The policy of the National Bureau of Standards is to encourage and lead in national use of the metric system, formally called the International System of Units (SI).[1] The NBS guidelines[2] are intended to aid and expedite the transition from the use of non-SI to SI units in Bureau issuances, publications, and reports; they are to be implemented logically and equitably.

NBS practice is to use SI units in the publication of all descriptive and essential data (as defined below). SI units should be used by the NBS staff in both technical and non-technical publications and addresses. Exceptions are allowed when the intended audience would not comprehend such units. Until the national use of SI units prevails, exceptions to exclusive usage of SI units may be required in some NBS publications. The general rule is that exceptions must be determined by considering the audience for a given publication. If the readership would be limited by the exclusive use of SI units, customary units may be added in parentheses for scientific and technical publications as well as in press releases and issuances to the general public. The emphasis should be not only on communicating the contents, but also on familiarizing readers with the metric system. In public and technical presentations the NBS staff should aid the audience in thinking metric; speakers should acquaint the audience with SI units if these units are not ordinarily used by the listeners. Exceptions to the exclusive use of SI units should be used to educate both technical and non-technical audiences in SI units and their use. An exception should not be invoked as a precedent for prolonging the use of non-SI units.

The transition period to the predominant national use of the metric system is not sharply defined. NBS leadership in this national adoption of SI units will be more effective if the transition within NBS is as complete and as rapid as possible. The staff is urged to remember this fact in the preparation of all NBS presentations and publications.

All numerical data, both descriptive and essential, are affected by this policy.

Descriptive data describe arrangements, environments, noncritical dimensions and shapes of apparatus, and similar measurements not affecting calculations or results. Such data should be expressed in SI units unless this makes the expression excessively complicated. For example, commercial gauge designations, commonly used items identified by nominal dimensions, or other commercial nomenclatures (such as drill sizes, or standards for weights and measures) expressed in customary units are acceptable.

Essential data express, precede, or interpret the quantitative results being reported. All such data should be expressed solely in SI units except in those fields where (a) the sole use of SI units would create a serious impediment to communications, or (b) SI units have not been specified. Exceptions may also occur when dealing

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These guidelines are an important part of NBS commitment to the greatest practicable use of the International System of Units (SI) in all of our publications and also in all of our dealings and correspondence with the science and engineering communities and the public.

Two recent developments make necessary this revision of our guidelines for the use of SI: (1) the issuance of the Federal Register Notice of December 10, 1976,* in accordance with the Metric Conversion Act of 1975 (PL 94–168), and (2) the issuance of the 1977 Edition of NBS Special Publication 330, The International System of Units (SI).

I urge all of you to keep these guidelines handy and to use SI to the fullest possible extent. If you need further help or additional information on SI, call on your Editorial Review Board or on the Chief, Office of Technical Publications. They are available and anxious to assist in uniform and correct SI usage.

E. Ambler.

Ernest Ambler
Acting Director

*Superseded by notice of October 26, 1977

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[1] The International System of Units (SI) was defined and given official status by the 11th General Conference on Weights and Measures, 1960. A complete listing of the SI units of weights and measures is presented in detail in NBS Spec. Pub. 330, 1977 Edition. See also The Metric System: SI page 2 and Appendix 1, page 3.

[2] These guidelines supersede LC1056 August 1975.

with commercial devices, standards, or units having some legal definition, such as commercial weights and measures. Even in such instances, SI units should be used when practical and meaningful; for example, this may be done by adding non-SI units in parentheses after SI units. In tables, SI and customary units may be shown in parallel columns. In graphs, a secondary set of coordinate markings in non-SI units may also be included. The top and right-hand sides of a graph are often appropriate for this purpose.

The Metric System: SI

The SI is constructed from seven base units for independent quantities plus two supplementary units for plane angle and solid angle. (See Table 1.) Units for all other quantities are derived from these nine units. In Table 2 are listed 18 SI derived units with special names which were derived from the base and supplementary units in a coherent manner, which means in brief, that they are expressed as products and ratios of the nine base and supplementary units without numerical factors. All other SI derived units, such as those in tables 3 and 4, are similarly derived in a coherent manner from the 27 base, supplementary, and special-name SI units. For use with the SI units there is a set of 16 prefixes (see table 5) to form multiples and submultiples of these units. For mass the prefixes are to be applied to the gram instead of to the SI unit, the kilogram.

The SI units together with the SI prefixes provide a logical and interconnected framework for measurements in science, industry, and commerce. Along with leading national and international professional and standardizing bodies, NBS encourages familiarity with, and diffusion of, SI units throughout all sectors of United States activities.

Fundamental Constants/Natural Units

In some cases quantities are commonly expressed in terms of fundamental constants of nature, and the use of these constants or "natural units" is acceptable. The author, however, should state clearly which natural units are being used; such broad terms as "atomic units" should be avoided when there is danger of confusion. Typical examples of natural units are:

Unit	Symbol
elementary charge	e
electron mass	m_e
proton mass	m_p
Bohr radius	a_0
electron radius	r_e
Compton wavelength of electron	λ_C
Bohr magneton	μ_B
nuclear magneton	μ_N
speed of light	c
Planck constant	h

For additional examples, see "Fundamental Constants," *Dimensions/NBS,* Jan. 1974.

Units Acceptable for Use with SI

Certain units which are not part of the SI are used so widely that it is impractical to abandon them. The units that are accepted by NBS for continued use with the International System are listed in table 6. In those cases where their usage is already well established, the International Committee for Weights and Measures (CIPM) also has authorized, for a limited time, the use of the common units shown with an asterisk in table 7.

The short names for compound units (such as "coulomb" for "ampere second" and "pascal" for "newton per square meter") exist for convenience, and either form is correct (see table 2). For example, communication sometimes is facilitated if the author expresses magnetic flux in the compound term volt seconds (instead of using the synonym, webers) because of the descriptive value implicit in the compound phrase.

In some specialized fields (e.g., magnetism in material media), the appropriate quantities are still to be determined. Guidelines for these cases are flexible. Use of a table of conversion may be misleading, and it may even be preferred to compare different physical quantities in different systems of units.

Special Considerations

The kelvin (K) is the SI base unit of temperature; this unit is properly used for expressing temperature and temperature intervals. However, wide use is also made of the degree Celsius (°C) for expressing temperature and temperature intervals. The Celsius scale (formerly called centigrade) is related directly to thermodynamic temperature (kelvins) as follows:

The temperature interval one degree Celsius equals one kelvin exactly.

Celsius temperature (t) is related to thermodynamic temperature (T) by the equation:

$$t = T - T_0$$

where $T_0 = 273.15$ K by definition.

Logarithmic measures such as pH, dB, and Np are acceptable.

Words and symbols should not be mixed. If mathematical operations are indicated, for example, only symbols should be used. Any of the forms "joules per mole," "J/mol," "J·mol^{-1}" is considered good usage but the forms "joules/mole" and "joules·mol^{-1}" are not. See appendix 2 for additional rules.

In all government printing of the National Bureau of Standards, the spellings "meter" and "liter" are to be used.

Over the years the term *weight* has been used to designate two quantities: *mass* and *force*. In conformity with the recommendation in the American National Standard for Metric Practice quoted in Appendix 3, the term *weight* will not be used in NBS publications except under circumstances in which its meaning is completely clear.

Implementation

NBS policy for the use of SI in its public documents is explicit. The staff is urged to aid in its implementation to the fullest degree practicable. Although the Bureau recognizes the necessity for a transitional period of education and adjustment, these guidelines are designed to place greater emphasis on the use of SI than before.

The provisions of this document are a part of the editorial approval criteria for all NBS writings undergoing review by division and Bureau editorial review boards. In addition, NBS staff members are urged to aid in the diffusion of the knowledge of SI units through all modes of communication including talks, correspondence, etc.

For additional information on the use of SI units, the NBS staff should obtain and use the following publications which are available in the NBS Storeroom:

NBS SP330, 1977 Edition, "The International System of Units: SI"

ISO International Standard 1000 (1973 Edition) "SI Units and Recommendations for Use of Their Multiples"

American National Standard Z210.1-1976, American Standard for Metric Practice

Examples of conversion factors from non-SI units to SI are provided in table 7.

Appendix 1
Units and Conversion Factors

TABLE 1

SI base and supplementary units

Quantity	Name	Symbol
SI base units		
length	meter	m
mass[1]	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd
SI supplementary units		
plane angle	radian	rad
solid angle	steradian	sr

[1] "Weight" is the commonly used term for "mass."

TABLE 2

SI derived units with special names

Quantity	SI unit			
	Name	Symbol	Expression in terms of other units	Expression in terms of SI base units
frequency	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	$m^2\cdot kg\cdot s^{-3}$
quantity of electricity, electric charge	coulomb	C	$A\cdot s$	$s\cdot A$
electric potential, 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	$m^2\cdot kg\cdot s^{-3}\cdot A^{-2}$
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	$kg\cdot s^{-2}\cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2\cdot kg\cdot s^{-2}\cdot A^{-2}$
Celsius temperature[a]	degree Celsius	°C		K
luminous flux	lumen	lm		$cd\cdot sr$[b]
illuminance	lux	lx	lm/m^2	$m^{-2}\cdot cd\cdot sr$[b]
activity (of a radionuclide)	becquerel	Bq		s^{-1}
absorbed dose, specific energy imparted, kerma, absorbed dose index	gray	Gy	J/kg	$m^2\cdot s^{-2}$

[a] See Special Considerations, p. 2.
[b] In this expression the steradian (sr) is treated as a base unit.

TABLE 3

Some SI derived units expressed in terms of base units

Quantity	SI unit	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	1 per meter	m^{-1}
density, mass density	kilogram per cubic meter	kg/m^3
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
specific volume	cubic meter per kilogram	m^3/kg
luminance	candela per square meter	cd/m^2

TABLE 4

Some SI derived units expressed by means of special names

Quantity	SI unit		
	Name	Symbol	Expression in terms of SI base units
dynamic viscosity	pascal second	Pa·s	$m^{-1}\cdot kg\cdot s^{-1}$
moment of force	newton meter	N·m	$m^2\cdot kg\cdot s^{-2}$
surface tension	newton per meter	N/m	$kg\cdot s^{-2}$
power density, heat flux density, irradiance	watt per square meter	W/m^2	$kg\cdot s^{-3}$
heat capacity, entropy	joule per kelvin	J/K	$m^2\cdot kg\cdot s^{-2}\cdot K^{-1}$
specific heat capacity, specific entropy	joule per kilogram kelvin	J/(kg·K)	$m^2\cdot s^{-2}\cdot K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2\cdot s^{-2}$
thermal conductivity	watt per meter kelvin	W/(m·K)	$m\cdot kg\cdot s^{-3}\cdot K^{-1}$
energy density	joule per cubic meter	J/m^3	$m^{-1}\cdot kg\cdot s^{-2}$
electric field strength	volt per meter	V/m	$m\cdot kg\cdot s^{-3}\cdot A^{-1}$
electric charge density	coulomb per cubic meter	C/m^3	$m^{-3}\cdot s\cdot A$
electric flux density	coulomb per square meter	C/m^2	$m^{-2}\cdot s\cdot A$
permittivity	farad per meter	F/m	$m^{-3}\cdot kg^{-1}\cdot s^4\cdot A^2$
permeability	henry per meter	H/m	$m\cdot kg\cdot s^{-2}\cdot A^{-2}$
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·K)	$m^2\cdot kg\cdot s^{-2}\cdot K^{-1}\cdot mol^{-1}$
exposure (x and γ rays)	coulomb per kilogram	C/kg	$kg^{-1}\cdot s\cdot A$
absorbed dose rate	gray per second	Gy/s	$m^2\cdot s^{-3}$

TABLE 5

SI prefixes

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

TABLE 6

Units in use with the International System

Name	Symbol	Value in SI unit
minute	min	1 min = 60 s
hour	h	1 h = 60 min = 3 600 s
day	d	1 d = 24 h = 86 400 s
degree	°	1° = $(\pi/180)$ rad
minute	′	1′ = (1/60)° = $(\pi/10\ 800)$ rad
second	″	1″ = (1/60)′ = $(\pi/648\ 000)$ rad
liter	L*	1 L = 1 dm^3 = 10^{-3} m^3
metric ton (tonne)	t	1 t = 10^3 kg
hectare	ha	1 ha = 10^4 m^2

* The international symbol for liter is "l", which can be easily confused with the numeral "1". Accordingly, the symbol "L" is recommended for United States use.

TABLE 7

Examples of conversion factors from non-SI units to SI

Physical Quantity	Name of Unit	Symbol for Unit	Definition in SI Units
length	inch	in	2.54 x 10^{-2} m
length	nautical mile*	nmi	1852 m
length	angstrom*	Å	10^{-10} m
velocity	knot*	kn	(1852/3600) m/s
cross section	barn*	b	10^{-28} m^2
acceleration	gal*	Gal	10^{-2} m/s^2
mass	pound (avoirdupois)	lb	0.453 592 37 kg
force	kilogram-force	kgf	9.806 65 N
pressure	conventional millimeter of mercury	mmHg	13.5951 x 9.806 65 $N\cdot m^{-2}$
pressure	atmosphere*	atm	101 325 $N\cdot m^{-2}$
pressure	torr	Torr	(101 325/760) $N\cdot m^{-2}$
pressure	bar*	bar	10^5 Pa
stress	pound-force per sq. inch	lbf/in^2	6 894.757 Pa
energy	British thermal unit**	Btu	1055.056 J
energy	kilowatt hour	kWh	3.6 x 10^6 J
energy	calorie (thermochemical)	cal	4.184 J
activity (of a radio-nuclide)	curie*	Ci	3.7 x 10^{10} Bq
exposure (x or γ rays)	röntgen*	R	2.58 x 10^{-4} $C\cdot kg^{-1}$
absorbed dose	rad*	rd	1 x 10^{-2} Gy

* The CIPM has sanctioned the temporary use of these units.
**International Table

Appendix 2

Writing Style Guides

1. CAPITALS
   Units: When written in full, the names of all units start with a lowercase letter, except at the beginning of a sentence. Note that in degree Celsius the unit "degree" is lowercase but the modifier "Celsius" is capitalized. The "degree centigrade" is obsolete.
   Symbols: Unit symbols are written with lowercase letters except that the first letter is uppercase when the name of the unit is derived from the name of a person and (2) the symbol for liter is capital L.
   Prefixes: The symbols for numerical prefixes for exa(E), peta(P), tera(T), giga(G), and mega (M) are written with uppercase letters, all others with lowercase letters. All prefixes are written in lowercase letters when written out in full, except where the entire unit name is written in uppercase letters.
2. PLURALS
   a. When written in full, the names of units are made plural when appropriate. Fractions both common and decimal are always singular.
   b. Symbols for units are the same in singular and plural (no "s" is ever added to indicate a plural).
3. PERIODS
   A period is NOT used after a symbol, except at the end of a sentence.
4. THE DECIMAL POINT
   The dot is used as the decimal point and is placed on the line. In numbers less than one, a zero must be written before the decimal point.
5. GROUPING OF DIGITS
   a. Separate digits into groups of three, counting from the decimal sign. The comma should not be used. Instead, a space is left to avoid confusion, since many countries use a comma for the decimal point.
   b. In numbers of four digits, the space is not recommended, unless four-digit numbers are grouped in a column with numbers of five digits or more.
6. SPACING
   a. In symbols or names for units having prefixes, *no* space is left between letters making up the symbol or the name.
   b. When a symbol follows after a number to which it refers, a space must be left between the number and the symbol (except for degree, minute, and second of angle).
7. COMPOUND UNITS
   In the symbol for a compound unit that is formed by the multiplication of two or more units, a centered dot is used. For example N•m.
   In the name for such a unit, a space is recommended (or a hyphen is permissible) but never a centered dot. For example, newton meter or newton-meter.

Appendix 3

Quotation from the American National Standard for Metric Practice, Z210.1-1976

3.4.1.1 The principal departure of SI from the gravimetric system of metric engineering units is the use of explicitly distinct units for mass and force. In SI, the name kilogram is restricted to the unit of mass, and the kilogram-force (from which the suffix *force* was in practice often erroneously dropped) should not be used. In its place the SI unit of force, the newton, is used. Likewise, the newton rather than the kilogram-force is used to form derived units which include force, for example, pressure or stress ($N/m^2 = Pa$), energy ($N{\cdot}m = J$), and power ($N{\cdot}m/s = W$).

3.4.1.2 Considerable confusion exists in the use of the term *weight* as a quantity to mean either *force* or *mass*. In commercial and everyday use, the term *weight* nearly always means mass; thus, when one speaks of a person's weight, the quantity referred to is mass. This nontechnical use of the term weight in everyday life will probably persist. In science and technology, the term *weight of a body* has usually meant the force that, if applied to the body, would give it an acceleration equal to the local acceleration of free fall. The adjective "local" in the phrase "local acceleration of free fall" has usually meant a location on the surface of the earth; in this context the "local acceleration of free fall" has the symbol g (sometimes referred to as "acceleration of gravity") with observed values of g differing by over 0.5% at various points on the earth's surface. The use of *force of gravity* (mass times acceleration of gravity) instead of *weight* with this meaning is recommended. Because of the dual use of the term weight as a quantity, this term should be avoided in technical practice except under circumstances in which its meaning is completely clear. When the term is used, it is important to know whether mass or force is intended and to use SI units properly as described in 3.4.1.1, by using kilograms for mass or newtons for force.