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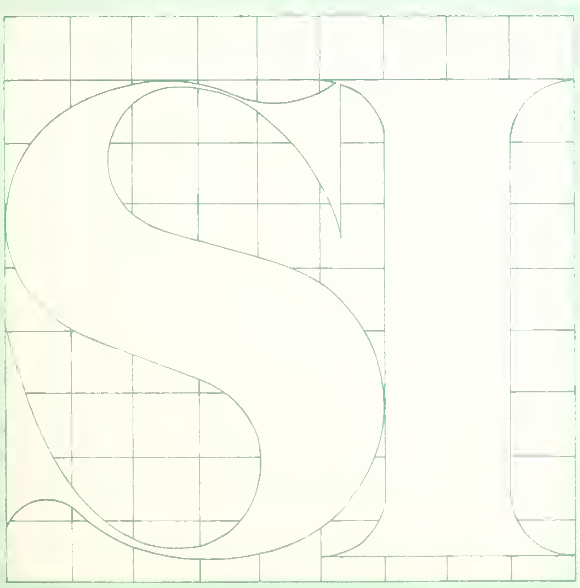
LC 1120
Supersedes LC 1056

Guidelines for Use of the MODERNIZED METRIC SYSTEM



Actions at the 1979 General Conference on Weights and Measures (CGPM)*

Since the last publication of the NBS guidelines for the use of the International System of Units (SI) in 1977, three important actions concerning SI have been taken by the General Conference on Weights and Measures. This revised version of the NBS guidelines reflects these decisions.

At their meeting in Paris, France, October 8-12, 1979, the General Conference:

(1) Redefined the base SI unit candela to read—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 of which the radiant intensity in that direction is 1/683 watt per steradian.

(2) Adopted the special name sievert, symbol Sv, for the SI unit of dose equivalent in the field of radiological protection. The sievert is equal to one joule per kilogram.

(3) Adopted l and L as alternative symbols for the unit liter.

E. Ambler

Ernest Ambler
Director

*E. Ambler was the U.S. delegate to the CGPM, accompanied by advisors Francis X. Cunningham (Department of State), Edward L. Brady (NBS), and Abraham S. Friedman (American Embassy, Paris).

The International System of Units

THE following Guidelines have been adopted by the National Bureau of Standards of the U.S. Department of Commerce for use of the International System of Units (SI),[1] informally called the metric system.

These Guidelines[2] reflect the decisions of the General Conference on Weights and Measures (CGPM) and its subordinate Committees which defined the modernized metric system and gave offi-

[1] *The International System of Units (SI) was initially defined and given official status by the 11th General Conference on Weights and Measures, 1960. A complete listing of the SI units is presented in NBS Special Publication 330, 1977 Edition. A summary of the SI is given in Appendix 1 of this document.*

[2] *These Guidelines supersede LC 1056 dated November 1977 and those that appeared in DIMENSIONS/NBS, October 1977.*

cial status to SI in 1960. The United States holds a place on these international bodies by virtue of its adherence to the Treaty of the Meter, signed in 1875. The National Bureau of Standards acts as the official U.S. representative to the various international bodies formed by the Treaty.

The National Bureau of Standards, in light of the Metric Conversion Act of 1975, recommends the use of metric units except in contexts where the exclusive use of metric units would needlessly confuse the intended audience. In these cases, the dual use of metric and inch-pound (customary) units may serve the two purposes of not only communicating the contents but also familiarizing the readers with the new metric system.

In all cases, NBS recommends a common-sense approach to metric conversion. These Guidelines are meant to provide NBS recommendations on the use of the modernized metric system while recognizing the evolving nature of metric practice in the U.S.

For further information concerning metric conversion in the United States, the reader should contact the U.S. Metric Board, 1815 N. Lynn Street, Suite 600, Arlington, VA 22209. For further information about the metric system, contact the NBS Office of Technical Publications, Washington, D.C. 20234.

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 19 SI derived units with special names. These units are derived from the base and supplementary units in a coherent manner, which means they are expressed as products and quotients 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 28 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 base unit, the kilogram.

The SI units together with the SI prefixes provide a logical and interconnected framework for measurements in science, industry, and commerce. NBS encourages the use of SI in the United States.

Fundamental Constants/Natural Units

In some cases, quantities are commonly expressed in terms of fundamental constants of nature, and 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_o
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

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 for continued use with the International System are listed in table 6. It is likewise necessary to recognize, outside the International System, the following units which are used in specialized fields:

Unit	Symbol
electron volt	eV
unified atomic mass unit	u
astronomical unit	AU
parsec	pc

The units shown with an asterisk in table 7 are used in limited fields and have been authorized by the International Committee for Weights and Measures (CIPM), the international committee that guides the technical work of the Treaty of the Meter, for temporary use in those fields.

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, weber) because of the descriptive value implicit in the compound phrase.

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:

$$t = T - T_0$$

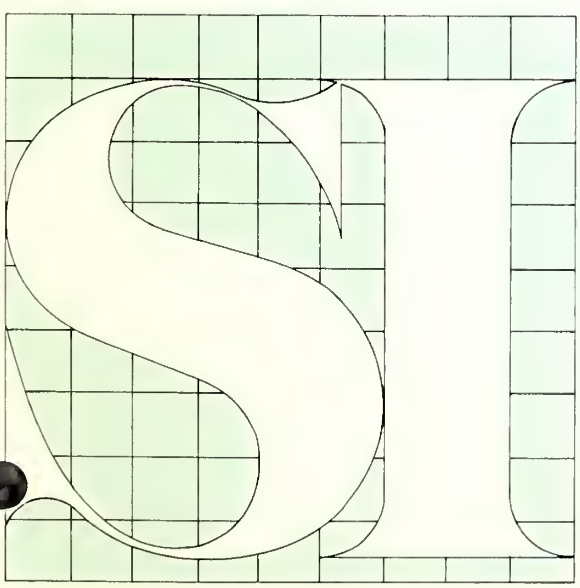
where $T_0 = 273.15$ K by definition.

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," "$J \cdot mol^{-1}$" is considered good usage, but the forms "joules/mole" and "$joules \cdot mol^{-1}$" are not. See Appendix 2 for additional rules.

Logarithmic measures such as pH, dB (decibel), and Np (neper) are acceptable.

Over the years the term *weight* has been used to designate two quantities: *mass* and *force*. NBS supports the recommendation in the American National Standard for Metric Practice quoted in Appendix 3, that the term *weight* should be avoided in technical publications except under circumstances in which its meaning is completely clear.

It is also recommended that the terms *atomic weight* and *molecular weight* be replaced by *relative atomic mass* and *relative molecular mass* in accordance with established international practice.[3]



Descriptive and Essential Data

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 inch-pound units are acceptable.

Essential data express or interpret the quantitative results being reported. All such data shall 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 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 inch-pound units may be shown in parallel columns. If coordinate markings in non-SI units are included in graphs, they should be displayed on the top and right-hand sides of the figure.

Additional References

For additional information on the use of SI units, the reader is directed to the following publications:

NBS SP 330, 1977 Edition, "The International System of Units: SI," the translation of the official text, "Le Système International d'Unités," (1977).

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.

[3] *ISO 31/VIII "Quantities and Units of Physical Chemistry and Molecular Physics."*

APPENDIX 1
Units and Conversion Factors

TABLE 1. SI base and supplementary units

	Quantity*	Unit Name	Unit Symbol
	length	meter	m
	mass[1]	kilogram	kg
SI base units	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] See Appendix 3 for a discussion of the terms "mass" and "weight."
* Quantity here and in Tables 2, 3, 4, and 7 means a measurable attribute.

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·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·s	s·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·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·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	$m^2 \cdot s^{-2}$
dose equivalent, dose equivalent index	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$

[a] See Special Considerations, p.15.
[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**

	SI Unit		
Quantity	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° = (π/180) rad
minute	′	1′ = (1/60)° = (π/10 800) rad
second	″	1″ = (1/60)′ = (π/648 000) rad
liter	L*	1 L = 1 dm^3 = 10^{-3} m^3
metric ton	t	1 t = 10^3 kg
hectare	ha	1 ha = 10^4 m^2

* An alternative symbol for liter is "l". Since "l" can be easily confused with the numeral "1," the symbol "L" is recommended for United States use.

TABLE 7. **Examples of conversion factors from non-SI units to SI**

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	millimeter of mercury at 0°C	mmHg	133.322 Pa†
pressure	atmosphere	atm	101 325 Pa
pressure	torr	Torr	(101 325/760) Pa
pressure	# bar*	bar	10^5 Pa
stress	pound-force per sq in	lbf/in^2	6 894.757 Pa†
energy	British thermal unit (Int. Table)	Btu	1055.056 J†
energy	kilowatt hour	kWh	3.6 x 10^6 J
energy	calorie (thermochemical)	cal	4.184 J
activity (of a radionuclide)	curie*	Ci	3.7 x 10^{10} Bq
exposure (x or γ rays)	roentgen*	R	2.58 x 10^{-4} $C \cdot kg^{-1}$
absorbed dose	rad*	rd	1 x 10^{-2} Gy
dose equivalent	rem*	rem	1 x 10^{-2} Sv

* The CIPM has sanctioned the temporary use of these units.
† Approximate; all other conversion factors are exact.

#The use of these units is discouraged in the American National Standard for Metric Practice, Z210.1

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 or in capitalized material such as a title. 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 (1) 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 MARKER

The dot (point) is used as the decimal marker 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. Digits should be separated into groups of three, counting from the decimal marker. The comma should not be used. Instead, a space is left to avoid confusion, since many countries use a comma for the decimal marker.

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 that have prefixes, no space is left between letters making up the symbol or the name.

b. When a symbol follows 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 of 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 (commonly referred to as "acceleration of gravity") with observed values of g differing by over 0.5 percent 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. □