

American National Standard for Metric Practice

adopted by the
Department of Defense
United States of America
see last page of text
for acceptance notice

*General Conference of
Weights and Measures*

*General Committee for
Weights and Measures*

*International System
of Units (SI)*

Metrication

Units Permitted With SI

Letter Symbols

Conversion Factors

Standards Coordinating Committees

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

ANSI/IEEE Std 268-1992



Published by the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017, USA.

October 28, 1992

SH15529

Recognized as an
American National Standard (ANSI)

ANSI/IEEE
Std 268-1992
(Revision of ANSI/IEEE
Std 268-1982)

American National Standard for Metric Practice

Sponsor

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

Approved March 19, 1992

IEEE Standards Board

Approved September 15, 1992

American National Standards Institute

Abstract: Guidance for the application of the modernized metric system in the United States 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 limited list of non-SI units recognized for use with SI units, and a list of conversion factors from non-SI to SI units, 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*

NOTE: See the last page for adoption notices.

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

Copyright ©1992 by the
Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 1992
Printed in the United States of America

ISBN 1-55937-246-X

*No part of this publication may be reproduced in any form,
in an electronic retrieval system or otherwise,
without the prior written permission of the publisher.*

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

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

IEEE Standards documents are adopted by the Institute of Electrical and Electronics Engineers without regard to whether their adoption may involve patents on articles, materials, or processes. Such adoption does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the standards documents.

Foreword

(This foreword is not a part of ANSI/IEEE Std 268-1992, American National Standard for Metric Practice.)

This latest edition of the primary American National Standard on metric practice appears as interest in metric conversion in the United States is increasing. The US Congress, in the Omnibus Trade and Competitiveness Act of 1988, declared that it is "the policy of the United States (1) to designate the metric system of measurement as the preferred system of weights and measurements for United States trade and commerce; (2) to require that each Federal Agency, by a date certain and to the extent economically feasible by the end of fiscal year 1992, use the metric system of measurements in its procurements, grants, and other business-related activities . . ." ANSI/IEEE Std 268-1992 has been recommended for use by all departments and agencies of the federal government.

This revision contains the latest recommendations of the General Conference on Weights and Measures, including the four new SI prefixes that were adopted in 1991. The rules for handling unit symbols have been modified slightly to bring them more closely into conformance with international standards, and the table of conversion factors has been thoroughly revised to make it easier to use.

At the time this standard was approved, the membership of working group SCC14.1 was as follows:

Bruce B. Barrow
John Benedict
Marianne Brogan
Bradley E. Copeland
Andrew F. Dunn
John A. Goetz
David T. Goldman
Truman S. Gray
Harry M. Hesse

John Howard
A. Ivan Johnson
Ronald K. Jurgen
Karl G. Kessler
William R. Kruesi
Chris E. Kuyatt
Joseph G. Langenstein
Marie Longyear-Dunphy
Jack M. Loudon

Arthur O. McCoubrey
Conrad R. Muller
Chester H. Page
John T. Scott
Ralph M. Showers
Joe D. Simmons
John Tascher
Barry N. Taylor
Alan S. Whelihan

The following persons were on the balloting committee that approved this document for submission to the IEEE Standards Board:

Bruce B. Barrow
Andrew F. Dunn
John A. Goetz
Truman S. Gray
Harry M. Hesse

Ronald K. Jurgen
William R. Kruesi
Jack M. Loudon
Arthur O. McCoubrey

Conrad R. Muller
Chester H. Page
Ralph M. Showers
Barry N. Taylor
Alan S. Whelihan

When the IEEE Standards Board approved this standard on March 19, 1992, it had the following membership:

Marco W. Migliaro, *Chair*

Donald C. Loughry, *Vice Chair*

Andrew G. Salem, *Secretary*

Dennis Bodson
Paul L. Borrill
Clyde Camp
Donald C. Fleckenstein
Jay Forster*
David F. Franklin
Ramiro Garcia
Thomas L. Hannan

Donald N. Heirman
Ben C. Johnson
Walter J. Karplus
Ivor N. Knight
Joseph Koepfinger*
Irving Kolodny
D. N. "Jim" Logothetis
Lawrence V. McCall

T. Don Michael*
John L. Rankine
Wallace S. Read
Ronald H. Reimer
Gary S. Robinson
Martin V. Schneider
Terrance R. Whittemore
Donald W. Zipse

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Satish K. Aggarwal
James Beall
Richard B. Engelman
Stanley Warshaw

Mary Lynne Nielsen
IEEE Standards Project Editor

Contents

SECTION	PAGE
1. Scope	9
2. SI Units and Symbols	9
2.1 Classes of Units	9
2.2 Base Units	9
2.3 Supplementary Units	9
2.4 Derived Units	10
2.5 SI Prefixes	10
2.5.1 Unit of Mass	11
3. Application of SI	11
3.1 General	11
3.2 Application of SI Prefixes	13
3.2.1 General	13
3.2.2 Selection	14
3.2.3 Prefixes in Compound Units	14
3.2.4 Compound Prefixes	14
3.2.5 Powers of Units	14
3.2.6 Calculations	14
3.3 Other Units	14
3.3.1 Units From Different Systems	14
3.3.2 Units in Use With SI	14
3.3.3 Units in Use With SI Temporarily	16
3.3.4 Units and Names to Be Abandoned	16
3.4 Other Recommendations Concerning Units	17
3.4.1 Mass, Force, and Weight	17
3.4.2 Temperature	19
3.4.3 Nominal Dimensions	19
3.4.4 Torque and Work	19
3.4.5 Impact	20
3.4.6 Pressure and Vacuum	20
3.4.7 Quantities Expressed as Pure Numbers	20
3.5 Style and Usage	20
3.5.1 Rules for Writing Unit Symbols	20
3.5.2 Rules for Writing Names	21
3.5.3 Units Formed by Multiplication and Division	21
3.5.4 Numbers	22
3.5.5 Attachments to Unit Symbols	23
3.5.6 Pronunciation	23
4. Bibliography	24
APPENDIXES	
Appendix A Tables of Conversion Factors	27
A1. General	27
A2. Notation	27
A3. Use	27
A4. Organization	28

SECTION	PAGE
Appendix B Terminology.....	57
Appendix C Rules for Conversion and Rounding.....	59
C1. General.....	59
C2. Significant Digits.....	59
C3. Operations on Data.....	59
C4. Accuracy and Rounding.....	60
C5. Rounding Values.....	61
C6. Conversion of Linear Dimensions of Interchangeable Parts.....	62
C7. Other Units.....	64
Appendix D Development of the International System of Units (Le Système International d'Unités).....	67
D1. History.....	67
D2. Advantages of SI.....	68
D3. Selection of Units.....	69
D4. Definitions of SI Base Units.....	69
D5. Definitions of SI Supplementary Units.....	70
D6. Definitions of SI Derived Units With Special Names.....	70
Appendix E The BIPM and the Meter Convention.....	73
TABLES	
Table 1 Base SI Units.....	10
Table 2 Supplementary SI Units.....	10
Table 3 Derived SI Units With Special Names and Symbols.....	11
Table 4 Some Common Derived SI Units Without Special Names or Symbols.....	12
Table 5 SI Prefixes.....	13
Table 6 Units in Use With SI.....	15
Table 7 Units in Use With SI Temporarily.....	16
Table 8 Recommended Pronunciation of Prefixes.....	23
Table 9 Recommended Pronunciation of Selected Units.....	24
FIGURES	
Fig 1 Illustration of Difference Between Mass (Unit: kilogram) and Force (Unit: newton).....	18
APPENDIX TABLES	
Table A1 Classified List of Units—Space and Time.....	29
Table A2 Classified List of Units—Mechanics.....	33
Table A3 Classified List of Units—Heat.....	39
Table A4 Classified List of Units—Electricity and Magnetism.....	42
Table A5 Classified List of Units—Light.....	43
Table A6 Classified List of Units—Radiology.....	43
Table A7 Alphabetical List of Units.....	44
Table C1 Rounding Tolerance—Inches to Millimeters.....	62
Table C2 Conversion of Temperature Tolerance Requirements.....	64

American National Standard for Metric Practice

1. Scope

This document sets forth standard metric practice for the United States. Modern metric practice is based on the International System of Units, a system developed and maintained by the General Conference on Weights and Measures (abbreviated as CGPM from the official French name, *Conférence Générale des Poids et Mesures*) and intended as a basis for world-wide standardization of measurement units. The name International System of Units and the international abbreviation SI (from the French name, *Le Système International d'Unités*) were adopted by the 11th CGPM in 1960. SI is a complete, coherent system that is being universally adopted.

Information is included on SI, a limited list of non-SI units recognized for use with SI units, and a list of conversion factors from non-SI to SI units, together with general guidance on proper style and usage.

An understanding of SI and careful use according to this standard will help to avoid the degradation that has occurred in some previous measurement systems.

2. SI Units and Symbols

2.1 Classes of Units. SI units are divided into three classes:

- (1) Base units
- (2) Supplementary units
- (3) Derived units

Definitions of the units are given in Appendix D.

2.2 Base Units. SI is built upon the seven well-defined base units of Table 1,¹ which by convention are regarded as dimensionally independent.

2.3. Supplementary Units. This class contains two units, the radian and the steradian (see Table 2). 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

¹"Quantity" as used in the headings of the tables of this standard means a measurable attribute of phenomena or matter.

Measures of the CGPM) specified that in the International System the quantities plane angle and solid angle should be considered as dimensionless, derived quantities. Therefore, the supplementary units radian and steradian are to be regarded as dimensionless, derived units that may be used or omitted in expressing the units of physical quantities.

Table 1
Base SI 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.

Table 2
Supplementary SI Units

Quantity	Unit	Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

2.4 Derived Units. Derived units are formed by combining base units, supplementary units, and other derived 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 velocity is the *meter per second* (m/s or $\text{m}\cdot\text{s}^{-1}$), and that for angular velocity is the *radian per second* (rad/s or $\text{rad}\cdot\text{s}^{-1}$).

Those derived SI units that have special names and symbols approved by the CGPM are listed in Table 3. See also D6 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 for electric dipole moment is usually expressed as $\text{C}\cdot\text{m}$ instead of $\text{A}\cdot\text{s}\cdot\text{m}$.

Some common derived SI units without special names or symbols are listed in Table 4.

2.5 SI Prefixes (see 3.2 for application). 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.

Table 3
Derived SI Units With Special Names and Symbols

Quantity	Unit	Symbol	Formula
Absorbed dose, specific energy imparted, kerma, absorbed dose index	gray	Gy	J/kg
Activity (of a radionuclide)	becquerel	Bq	1/s
Celsius temperature*	degree Celsius	°C	K
Dose equivalent	sievert	Sv	J/kg
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·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 3.4.2 for a discussion of Celsius temperature.

These prefixes or their symbols are directly 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 D2) designated by the name “SI units,” namely, the base units, derived units, and supplementary units.

2.5.1 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 of decimal multiples and submultiples of the unit of mass are formed by attaching prefixes to the word *gram* or symbol *g*.

3. Application of SI

3.1 General. SI is the form of the metric system that should be used for all applications. It is important that this modernized form of the metric system be thoroughly understood and properly applied. This section gives guidance concerning the limited number of cases in which units outside SI are appropriately used and makes recommendations concerning usage and style.

Table 4
Some Common Derived SI Units Without Special Names or Symbols

Quantity	Unit	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	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.

Table 5
SI Prefixes

Multiplication Factor			Prefix	Symbol
1 000 000 000 000 000 000 000 000	=	10^{24}	yotta	Y
1 000 000 000 000 000 000 000	=	10^{21}	zetta	Z
1 000 000 000 000 000 000	=	10^{18}	exa	E
1 000 000 000 000 000	=	10^{15}	peta	P
1 000 000 000 000	=	10^{12}	tera	T
1 000 000 000	=	10^9	giga	G
1 000 000	=	10^6	mega	M
1 000	=	10^3	kilo	k
100	=	10^2	hecto*	h
10	=	10^1	deka*	da
0.1	=	10^{-1}	deci*	d
0.01	=	10^{-2}	centi*	c
0.001	=	10^{-3}	milli	m
0.000 001	=	10^{-6}	micro	μ
0.000 000 001	=	10^{-9}	nano	n
0.000 000 000 001	=	10^{-12}	pico	p
0.000 000 000 000 001	=	10^{-15}	femto	f
0.000 000 000 000 000 001	=	10^{-18}	atto	a
0.000 000 000 000 000 000 001	=	10^{-21}	zepto	z
0.000 000 000 000 000 000 000 001	=	10^{-24}	yocto	y

*To be avoided where practical, except as noted in 3.2.2.

3.2 Application of SI Prefixes

3.2.1 General. In general, the SI prefixes (see 2.5) should be used to indicate orders of magnitude, thus eliminating nonsignificant digits and leading zeros in decimal fractions, and providing a convenient alternative to the powers-of-ten notation preferred in computation. For example,

12 300 mm becomes 12.3 m
 12.3×10^3 m becomes 12.3 km
 0.001 23 μ A becomes 1.23 nA

3.2.2 Selection. When expressing a quantity by a numerical value and a unit, a prefix should preferably be chosen so that the numerical value lies between 0.1 and 1000. To minimize variety, it is recommended that prefixes representing 1000 raised to an integral power be used. However, the following factors may justify deviation from the above.

- (1) In expressing area and volume, the prefixes hecto-, deka-, deci-, and centi- may be required; for example, square hectometer, cubic centimeter.
- (2) In tables of values of the same quantity, or in a discussion of such values within a given context, it is generally preferable to use the same unit multiple throughout.
- (3) For certain quantities in particular applications, one particular multiple is customarily used. For example, the millimeter is used for linear dimensions in mechanical engineering drawings even when the values lie far outside the range 0.1 mm to 1000 mm; the centimeter is often 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. Only one prefix should be used in forming a multiple of a compound unit. Normally the prefix should be attached to a unit in the numerator. One exception to this is when the kilogram occurs in the denominator.

Examples: V/m, **not** mV/mm MJ/kg, **not** kJ/g

3.2.4 Compound Prefixes. Compound prefixes, formed by the juxtaposition of two or more SI prefixes, shall not be used. For example, use

1 nm, **not** 1 mμm
1 pF, **not** 1 μμF

If a value is required outside the range covered by the prefixes, it should be expressed by using a power of ten applied to the base 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 cm ³	= (10 ⁻² m) ³	= 10 ⁻⁶ m ³
1 ns ⁻¹	= (10 ⁻⁹ s) ⁻¹	= 10 ⁹ s ⁻¹
1 mm ² /s	= (10 ⁻³ m) ² /s	= 10 ⁻⁶ m ² /s

3.2.6 Calculations. Errors in calculations can be minimized if the base and the coherent derived SI units are used and if the resulting numerical values are expressed in powers-of-ten notation instead of using prefixes.

3.3 Other Units

3.3.1 Units From Different Systems. To assist in preserving the advantage of SI as a coherent system, it is advisable to minimize the use of units from other systems with SI. Such use should be limited to units listed in this section.

3.3.2 Units in Use With SI (See Table 6)

3.3.2.1 Time. The SI unit of time is the *second*. This unit is preferred and should be used if practical, particularly when technical calculations are involved. In cases where time relates to life customs or calendar cycles, the minute, hour, day, and other calendar units may be necessary. For example, vehicle speed will normally be expressed in kilometers per hour.

3.3.2.2 Plane Angle. The SI unit for plane angle is the *radian*. Use of the degree and its decimal submultiples is permissible when the radian is not a convenient unit. Use of the minute and second is discouraged except for special fields such as astronomy and cartography.

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).

3.3.2.4 Volume. The SI unit of volume is the *cubic meter*. This unit, or one of the regularly formed multiples such as the cubic centimeter, is preferred. The special name *liter* (symbol L) has been approved for the cubic decimeter, but use of this unit should be restricted to volumetric capacity, dry measure, and measure of fluids (both liquids and gases). No prefix other than milli or micro should be used with liter.

In October 1979, the CGPM approved L and l as alternative symbols for the liter. Since the letter symbol l can easily be confused with the numeral 1, only the symbol L is recommended for US use. Use of the script l as a symbol for liter is deprecated. See D3 for information concerning the history of this unit.

Table 6
Units in Use With SI

Quantity	Unit	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
	week, month, etc.		
Plane angle	degree*	°	1° = ($\pi/180$) rad
	minute*	'	1' = (1/60)° = ($\pi/10\ 800$) rad
	second*	"	1" = (1/60)' = ($\pi/648\ 000$) rad
Area	hectare	ha	1 ha = 1 hm^2 = 10 ⁴ m^2
Volume	liter†	L	1 L = 1 dm^3 = 10 ⁻³ m^3
Mass	metric ton‡	t	1 t = 10 ³ kg

*Decimal degrees should be used for division of degrees, except for special fields such as astronomy and cartography.

†See 3.3.2.4.

‡Also called "tonne." (See 3.3.2.5.)

3.3.2.5 Mass. The SI unit of mass is the *kilogram*. This unit, or one of the multiples formed by attaching an SI prefix to gram (g), is preferred for all applications. The megagram (Mg) is the appropriate unit for measuring large masses such as have been expressed in tons. However, 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 (also called "tonne" outside the USA) which is almost 2205 lb. None of these terms

are SI. The term “metric ton” should be restricted to commercial usage, and no prefixes should be used with it. Use of the term “tonne” is deprecated.

3.3.3 Units in Use With SI Temporarily (See Table 7)

3.3.3.1 Energy. The SI unit of energy, the *joule*, together with its multiples, is preferred for all applications. The kilowatthour is widely used, however, as a measure of electric energy. This unit should not be introduced into any new areas, and eventually it should be replaced by the megajoule.

Table 7
Units in Use With SI Temporarily

Quantity	Unit	Symbol	Definition
Absorbed dose	rad	rad*	1 rd = 0.01 Gy
Activity (of a radionuclide)	curie	Ci	1 Ci = 3.7×10^{10} Bq
Cross section (in particle scattering)	barn	b	1 b = 10^{-28} m ²
Dose equivalent	rem	rem	1 rem = 0.01 Sv
Energy (see 3.3.3.1)	kilowatthour	kWh	1 kWh = 3.6 MJ
Exposure (X & γ rays)	roentgen	R	1 R = 2.58×10^{-4} C/kg
Pressure (see 3.3.3.2)	bar	bar	1 bar = 10^5 Pa

*Where there is risk of confusion with the symbol for radian, rd may be used as the symbol for rad.

3.3.3.2 Pressure and Stress. The SI unit of pressure and stress is the *pascal* (newton per square meter) and with proper SI prefixes shall be applicable to all such measurements. (See also 3.4.6.) Old metric gravimetric units for pressure and stress such as kilogram-force per square centimeter (kgf/cm²) shall not be used. Widespread use has been made of other non-SI units, such as bar and torr for pressure, but this use is strongly discouraged.

The millibar has been widely used by meteorologists for communication within their profession; there is now some attempt to introduce the name “hectopascal” as a substitute for millibar. However, the kilopascal should be used in presenting meteorological data to the public.

3.3.4 Units and Names to Be Abandoned. A great many metric units other than those of the SI have been defined over the years. Some of these are used only in special fields; others have found broad application in countries that adopted the metric system early.

Except for the special cases discussed in the previous sections, non-SI units (as well as special names for multiples or submultiples of SI units) shall be avoided. Various categories of deprecated units are discussed in 3.3.4.1 to 3.3.4.4. The lists are not intended to be complete, but only to indicate more or less prominent examples of each category.

3.3.4.1 Centimeter-Gram-Second (CGS) Units. All units with special names peculiar to the various cgs systems (measurement systems constructed by using the centimeter, gram, and second as base units) shall be avoided. Among these units are the following, defined for mechanics, fluid mechanics, and photometry: the erg, dyne, gal, poise, stokes, stilb, phot, and lambert.

Further use of the cgs units of electricity and magnetism is deprecated. 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, statvolt, etc.

3.3.4.2 Decimal Multiples of SI Units. Those multiples of SI units that cannot be handled by using the SI prefixes are deprecated. Many such examples are covered in subsection 3.3.4.1. An additional example is the ångström (0.1 nm).

3.3.4.3 Unit Names to Be Avoided. Special names for multiples and submultiples of SI units are to be avoided except for the *liter* (3.3.2.4), *metric ton* (3.3.2.5), and *hectare* (3.3.2.3). For example:

Do Not Use		Use Instead	
are	1 are	$= 1 \text{ dam}^2$	$= 100 \text{ m}^2$
candle	1 candle	$= 1 \text{ cd}$	
candlepower	1 candlepower		$= 1 \text{ cd}$
fermi	1 fermi	$= 1 \text{ fm}$	$= 10^{-15} \text{ m}$
gamma	1 gamma	$= 1 \text{ nT}$	
micron	1 micron	$= 1 \mu\text{m}$	$= 10^{-6} \text{ m}$
millimicron	1 millimicron	$= 1 \text{ nm}$	$= 10^{-9} \text{ m}$
mho	1 mho	$= 1 \text{ S}$	
γ (mass)	1 γ	$= 1 \mu\text{g}$	
λ (volume)	1 $\lambda = \text{mm}^3$	$= 1 \mu\text{L}$	$= 1 \text{ mm}^3$

3.3.4.4 Miscellaneous Units. Other non-SI units that are deprecated include the following:

calorie
conventional millimeter of mercury
grade [1 grade = $(\pi/200)$ rad]
kilogram-force
langley [1 langley = 1 cal/cm^2]
metric carat
metric horsepower
millimeter, centimeter, or meter of water
standard atmosphere [1 atm = 101.325 kPa]
technical atmosphere [1 at = 98.0665 kPa]
torr

3.4 Other Recommendations Concerning Units

3.4.1 Mass, Force, and Weight

3.4.1.1 Distinction Between Units for Mass and Force. In the gravimetric systems of units, the same names (e.g., kilogram, pound, ounce) have often been used for 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 (see Fig 1). The kilogram-force (from which the suffix “force” in practice has often been erroneously dropped) shall not be used. Derived units that include force shall be formed using the newton. In all systems, distinct unit names shall be used; in the inch-pound system, for example, pound (lb) shall be restricted to mass, and pound-force (lbf) to force.

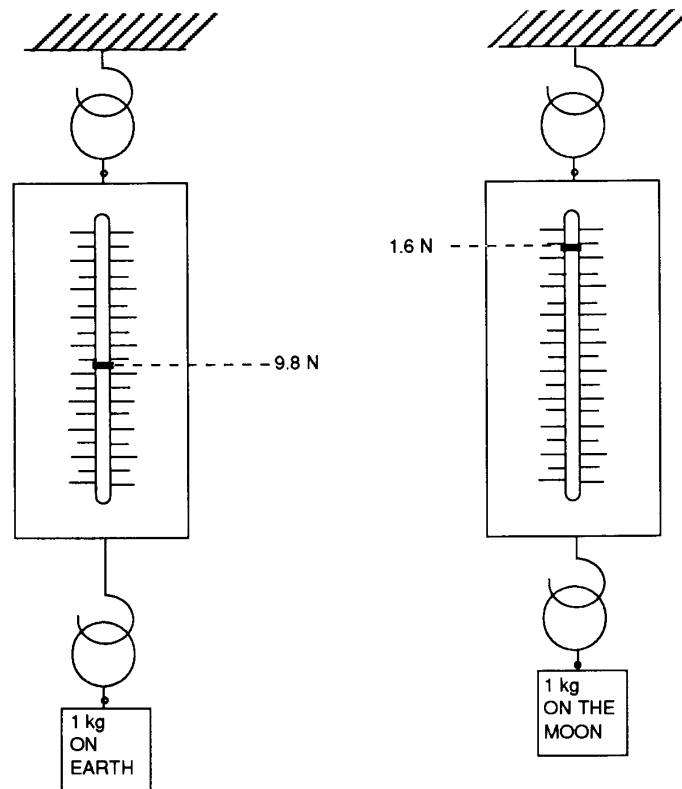


Fig 1
Illustration of Difference Between Mass (Unit: kilogram)
and Force (Unit: newton)

3.4.1.2 Weight. The term “weight” has been used to mean either mass or the force of gravity acting on the mass, and its representation in terms of SI units depends on how it is used.

In many technical fields and in commercial and everyday use, the term “weight” is usually used as a synonym for mass. Where the term is so used, weight is expressed in kilograms in SI. The verb “to weigh” means “to determine the mass of” or “to have a mass of.”

Examples: My weight is 60 kilograms.
 The suitcase weighs 12 kg.
 Net wt. 1 kg

In some fields of science and technology the term “weight” is defined as the force of gravity acting on an object, i.e., as the product of the mass of the object and the local acceleration of gravity. Where weight is so defined, it is expressed in newtons in SI. The terms “force of gravity” or “weight-force” should be used where this meaning is intended.

Examples: On Earth, the weight-force on a 10 kg mass is approximately 98 newtons. (Recommended)

On Earth, the weight of a 10 kg mass is approximately 98 newtons.
(Acceptable)

3.4.1.3 Load. The term “load” means either mass or force, depending on its use. A load that produces a vertically 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 shall be expressed in force units, i.e., newtons.

3.4.1.4 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 should be expressed in a mass unit rather than a force unit, thus in kilograms or metric tons, as appropriate, rather than newtons.

3.4.2 Temperature. The SI unit of thermodynamic temperature is the kelvin (K), and this unit is properly used for expressing thermodynamic temperature and temperature intervals. Wide use is also made of the degree Celsius ($^{\circ}\text{C}$), which is the SI unit used for expressing Celsius 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 $T_0 = 273.15 \text{ K}$ by definition.

In practice, the International Temperature Scale of 1990 (ITS-90) [B25]² 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 that exist in name only and are used for the purpose of convenient designation. Examples include the nominal 1 in pipe, the actual dimensions of which are given in appropriate standards, and “2 by 4” lumber. No attempt should be made to convert such nominal dimensions to SI.

3.4.4 Torque and Work

3.4.4.1 Torque. The determination of the correct SI units for torque and for other related quantities depends on whether the radian is used or omitted in expressions for derived units (see 2.3).

When the radian is omitted, the unit for torque is $\text{N}\cdot\text{m}$, the unit for moment of inertia is $\text{kg}\cdot\text{m}^2$, and the unit for moment of momentum is $\text{kg}\cdot\text{m}^2/\text{s}$. These units are convenient to use in the solution of problems in statics. In this case there is no problem with dimensional consistency.

When the radian is used, the unit for torque is $\text{N}\cdot\text{m}/\text{rad}$, the unit for moment of inertia is $\text{kg}\cdot\text{m}^2/\text{rad}^2$, and the unit for moment of momentum is $\text{kg}\cdot\text{m}^2/(\text{rad}\cdot\text{s})$. In the solution of problems that involve rotation, the use of these units will retain all advantages of dimensional analysis.

3.4.4.2 Work. The use of the unit $\text{N}\cdot\text{m}$ for bending moment or torque may result in confusion with the unit for work, which is also $\text{N}\cdot\text{m}$. If vectors were shown, the distinction between work and torque would be obvious, since work is the scalar product of force and displacement while torque is the vector product of force and moment arm. It is important to recognize this difference when $\text{N}\cdot\text{m}$ is used as the unit for torque. The joule, which is a special name for the SI unit of work, $\text{N}\cdot\text{m}$, should never be used as a name for the unit of torque.

²The numbers in brackets refer to the Bibliography in Section 4.

3.4.5 Impact. Impact strength (actually energy absorption) is measured in terms of energy required to break a standard specimen. The proper unit is joule.

3.4.6 Pressure and Vacuum. Gage pressure is absolute pressure minus ambient pressure (usually atmospheric pressure). Both gage pressure and absolute pressure are properly expressed in pascals, using SI prefixes as appropriate. Absolute pressure is never negative. Gage pressure is positive if above ambient pressure and negative if below. Pressure below ambient is often called vacuum; whenever 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.

3.4.7 Quantities Expressed as Pure Numbers. Certain so-called dimensionless quantities, as for example refractive index, relative permeability, 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 1.

Although special names for certain decimal fractions (such as percent, parts per thousand, and parts per million) are often used, to avoid confusion or misunderstanding it is preferable to use the proper exponential form, that is, 10^{-2} for percent, 10^{-3} for parts per thousand, and 10^{-6} for parts per million. Because the names of numbers one billion and larger are not uniform worldwide, terms such as parts per billion and parts per trillion should be strictly avoided. (See 3.5.4.2.)

In all cases, the meaning must be unequivocal. Expressions like “The volume fraction of CO_2 in the sample was 1.2×10^{-6} ” or “The mass fraction of CO_2 in the sample was 1.2×10^{-6} ” are permissible, but would not be permissible if the word “volume” in the first expression or “mass” in the second expression were not present.

3.5 Style and Usage

3.5.1 Rules for Writing Unit Symbols. Care must be taken to use unit symbols properly, and international agreement provides uniform rules.

- (1) Unit symbols shall be printed in roman (upright) type regardless of the type style used in the surrounding text.
- (2) Unit symbols shall be unaltered in the plural.
- (3) Unit symbols shall not be followed by a period except when used at the end of a sentence.
- (4) Letter unit symbols are written 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 2.5. Symbols retain their prescribed form regardless of the surrounding typography.
- (5) When 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, and 2.37 lm (for 2.37 lumens), **not** 2.37lm.

EXCEPTION: No space is left between the number and the symbols for degree, minute, and second of plane angle.

- (6) No space is used between the prefix and unit symbols.
- (7) Symbols, not abbreviations, should be used for units. For example, use “A”, and not “amp”, for ampere.

3.5.2 Rules for Writing Names. The handling of unit names varies internationally because of language differences, but use of the rules included here will improve communication in the English language.

- (1) 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.
- (2) Plurals are used when required by the rules of English grammar and are normally formed regularly, for example, henries for the plural of henry. The following irregular plurals are recommended:

Singular	Plural
lux	lux
hertz	hertz
siemens	siemens

- (3) No space or hyphen is used between the prefix and unit name. There are three cases where 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.
- (4) The spellings “meter,” “liter,” and “deka” are recommended. This is in accordance with guidance given by the US Department of Commerce, which is given the responsibility of interpreting SI for the United States under the Metric Conversion Act of 1975. The variant spellings “metre,” “litre,” and “deca” are also used, especially in British English.

3.5.3 Units Formed by Multiplication and Division

3.5.3.1 Unit Names

- (1) *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

- (2) *Quotient.* Use the word “per” and not a solidus:

meter per second, **not** meter/second

- (3) *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

This alternative is also allowed for derived units that include area or volume:

watt per square meter

NOTE: To avoid ambiguity in complicated expressions, symbols are preferred over words.

3.5.3.2 Unit Symbols. 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

$$\text{N}\cdot\text{m or N m}$$

In the case of W·h, watthour (a non-SI unit), the dot may be omitted, thus:

$$\text{Wh}$$

EXCEPTION: For computer printouts and other systems with limited character sets where the raised dot is not possible, a dot on the line may be used.

A compound unit that is a *quotient* of two or more units is indicated in one of the following ways:

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

In no case should more than one solidus be used in the same expression unless parentheses are inserted to avoid ambiguity. For example, write:

$$\text{J}/(\text{mol}\cdot\text{K}) \text{ or } \text{J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1} \text{ or } (\text{J}/\text{mol})/\text{K}, \text{ but not } \text{J}/\text{mol}/\text{K}$$

3.5.3.3 Mixtures. Symbols and unit names should not be mixed in the same expression. For example, write:

$$\text{joules per kilogram or J/kg}$$

Do not write

$$\text{joules/kilogram nor joules/kg nor joules}\cdot\text{kg}^{-1}$$

3.5.4 Numbers

3.5.4.1 Decimal Marker. The recommended decimal marker is a dot on the line. When writing numbers less than one, a zero should be written before the decimal marker.

Outside the United States, the comma is widely used as a 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 point toward the left and the right, and using a thin space to separate the groups. In numbers of four digits on either side of the decimal point 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.

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, the term should be avoided in technical writing.

3.5.4.3 Roman Numerals. The use of M to indicate thousands (as in MCF for thousands of cubic feet or in MCM for thousands of circular mils), of MM to indicate millions, of C to indicate hundreds, etc., is deprecated because of obvious conflicts with the SI prefixes.