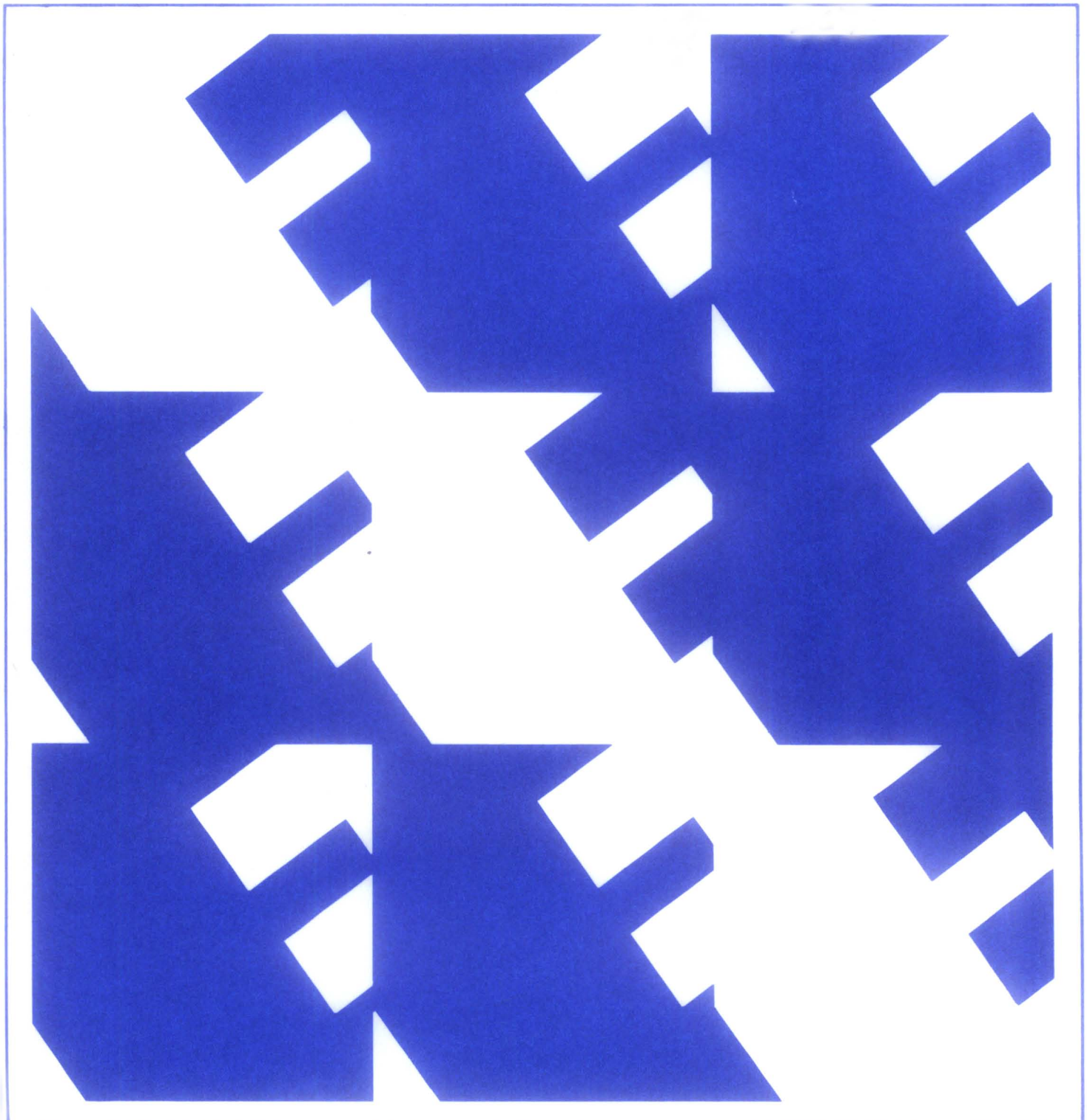


IEEE Standard Metric Practice

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ABSTRACT

This standard describes the International System of Units (SI), the modern version of the metric system. It includes listings of the base units, supplementary units, and units derived therefrom. Guidance is provided on application of the SI prefixes, other units in use with SI (including units accepted for limited use and units to be abandoned), and unit selection. A section on style and usage covers the writing of unit symbols and names, pronunciation, and recommendations for numbers. Extensive guidance is provided on conversion and rounding along with a very extensive table of conversion factors. An appendix provides background information in the development of SI.

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Foreword

(This Foreword is not a part of IEEE Std 268-1979, IEEE Standard Metric Practice.)

A new system of measurement, the International System of Units (SI), is being adopted throughout the world. This system is a modern version of the MKSA (meter, kilogram, second, ampere) system, and its details are published and controlled by an international treaty organization (see Appendix X2).

However, for a number of reasons, it is inevitable that a few other units outside the system be used with it. It is this additional use of non-SI units that leads to controversy and difference between standards that define modern metric practice.

Since a wide variety of metric units have been in use for years in various parts of the world, it is natural that tradition would promote use of these old units in formerly metric countries. For this reason many European and international standards also recognize a number of non-SI units for use.

To protect the new system from degradation, and to cooperate with knowledgeable people all over the world who are recommending good unit use, this standard strongly urges the use of SI, plus a very limited group of non-SI units, the need for which is strong and is widely endorsed. Accordingly, while this standard agrees with the major standards in the world on the description of SI, it differs from some in the list of additional units. While all the units recommended in this standard are also recommended in the national documents of other countries and in ISO 1000 (9)¹ some of the units recognized in these documents are not preferred for USA use, since proper suitable SI units are available for the quantities involved.

In this revision changes have been made to clarify some points, update references, and improve the table of conversion factors. To conform with new international recommendations the treatment of Celsius temperature and the International Practical Temperature Scale has been updated, and new items have been recognized: the unit for dose equivalent (the sievert), the use of L for liter, and the use of μ with the liter. New paragraphs are included on impact, pressure and vacuum, dimensionless quantities and on symbols for use in systems of limited character sets.

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¹The boldface numbers in parentheses refer to the list of references at the end of this standard.

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IEEE Standard Metric Practice

1. Scope

1.1 This standard gives guidance for application of the modernized metric system in the United States. The International System of Units, developed and maintained by the General Conference on Weights and Measures (abbreviated CGPM from the official French name *Conférence Générale des Poids et Mesures*) is intended as a basis for worldwide standardization of measurement units. The name International System of Units and the international abbreviation SI² were adopted by the 11th CGPM in 1960. SI is a complete, coherent system that is being universally adopted.

1.2 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.

1.3 It is hoped that an understanding of the system and its characteristics, and careful use according to this standard, will help to avoid the degradation that has occurred in all older measurement systems.

2. SI Units and Symbols

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

base units
supplementary units
derived units

2.2 **Base Units.** SI is based on seven well-defined units (See Table 1) which by convention are regarded as dimensionally independent.

² From the French name, *Le Système International d'Unités*.

³ "Quantity" as used in the headings of the tables of this standard means measurable attribute of phenomena or matter.

Table 1
Base SI Units

Quantity ³	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature ^a	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

^aFor a discussion of Celsius temperature see 3.4.2.

2.3 **Supplementary Units.** The General Conference has not yet classified certain units of the International System under either base units or derived units. These SI units are assigned to a class called "supplementary units" (See Table 2), and may be regarded either as base units or as derived units:

Table 2
Supplementary SI Units

Quantity ³	Unit	Symbol
plane angle	radian	rad
solid angle	steradian	sr

2.4 Derived Units.

2.4.1 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 $\text{rad} \cdot \text{s}^{-1}$).

2.4.2 Those derived SI units which have special names and symbols approved by the CGPM are listed in Table 3.

2.4.3 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 C·m instead of A·s·m.

2.4.4 Some common derived units are listed in Table 4.

2.5 SI Prefixes (see 3.2 for application).

2.5.1 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.

2.5.2 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* (g).

Table 3
Derived SI Units with Special Names

Quantity ³	Unit	Symbol	Formula
frequency (of a periodic phenomenon)	hertz	Hz	1/s
force	newton	N	kg·m/s ²
pressure, stress	pascal	Pa	N/m ²
energy, work, quantity of heat	joule	J	N·m
power, radiant flux	watt	W	J/s
quantity of electricity, electric charge	coulomb	C	A·s
electric potential, potential difference, electromotive force	volt	V	W/A
electric capacitance	farad	F	C/V
electric resistance	ohm	Ω	V/A
conductance	siemens	S	A/V
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m ²
inductance	henry	H	Wb/A
Celsius temperature	degree Celsius ^a	°C	K (See 3.4.2)
luminous flux	lumen	lm	cd·sr
illuminance	lux	lx	lm/m ²
activity (or a radionuclide)	becquerel	Bq	1/s
absorbed dose ^b	gray	Gy	J/kg
dose equivalent	sievert ^c	Sv	J/kg

^aInclusion in the Table of Derived SI Units with special names was approved by the CIPM in 1976.

^bRelated quantities using the same unit are: specific energy imparted, kerma, and absorbed dose index.

^cNot yet adopted by the CGPM, but approved by the CIPM in 1978.

2.5.3 These prefixes or their symbols are directly attached to names or symbols of units, forming multiples and submultiples of the units. In strict terms these must be called “multiples and submultiples of SI units,” particularly in discussing the coherence of the system. (See Section 5.) In common parlance, the base units and derived units, along with their multiples and submultiples, are all called SI units.

3. Application of the Metric System

3.1 General. SI is the form of the metric system that is preferred for all applications. It is important that this modernized form of the metric system be thoroughly understood and properly applied. Obsolete metric units and practices are widespread, particularly in those countries that long ago adopted the metric system, and much usage is improper. 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 5
SI Prefixes

Multiplication Factor	Prefix	Symbol
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 ^a	h
10 = 10 ¹	deka ^a	da
0.1 = 10 ⁻¹	deci ^a	d
0.01 = 10 ⁻²	centi ^a	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

^aTo be avoided where practical, except as noted in 3.2.2.

Table 4
Some Common Derived Units of SI

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 ^a	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

^aSee 3.4.4.

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
 0.00123 μA 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.

3.2.2.1 In expressing area and volume, the prefixes hecto-, deka-, deci-, and centi- may be required, for example, square hectometer, cubic centimeter.

3.2.2.2 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.

3.2.2.3 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 to 1000 mm; the centimeter is often used for body measurements and clothing sizes.

3.2.3 Prefixes in Compound Units.⁴ It is recommended that only one prefix 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, and MJ/kg, *not* kJ/g

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

1 nm, *not* 1 mμm
1 pF, *not* 1 μμF

If values are required outside the range covered by the prefixes, they should be expressed by using powers 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. For example:

$$\begin{aligned} 1 \text{ cm}^3 &= (10^{-2} \text{ m})^3 = 10^{-6} \text{ m}^3 \\ 1 \text{ ns}^{-1} &= (10^{-9} \text{ s})^{-1} = 10^9 \text{ s}^{-1} \\ 1 \text{ mm}^2/\text{s} &= (10^{-3} \text{ m})^2/\text{s} = 10^{-6} \text{ m}^2/\text{s} \end{aligned}$$

⁴A compound unit is a derived unit that is expressed in terms of two or more units, rather than by a single special name.

3.2.6 Calculations. Errors in calculations can be minimized if the base and the coherent derived SI units are used and 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 with it of units from other systems. 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 cartography.

3.3.2.3 Area. The SI unit of area is the square meter (m²). The hectare (ha) is a special name for the square hectometer (hm²). Large land or water areas are generally expressed in hectares or in square kilometers (km²).

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 liter⁵ (L)⁶ has been approved for the cubic decimeter, but use of this unit is restricted to the measurement of liquids and gases. No prefix other than milli- or micro- should be used with liter.

⁵See Appendix X1.11.1.

⁶The letter symbol l has been adopted for liter by the CIPM, and it is recommended in a number of international standards. In 1978 the CIPM accepted L as an alternative symbol, and it has been adopted in the national standards of the USA and Canada and in some other countries. Because of frequent confusion with the numeral 1 the letter symbol l is no longer recommended for USA use (see Federal Register notice of December 10, 1976). The script letter l, which had been proposed, is not recommended as a symbol for liter.

Table 6
Units in Use with SI

Quantity ³	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 ^a	'	1' = (1/60)°
			= ($\pi/10\,800$) rad
	second ^a	"	1" = (1/60)'
			= ($\pi/648\,000$) rad
area	hectare	ha	1 ha = 1 hm ² = 10 ⁴ m ²
volume	liter ^b	L	1 L = 1 dm ³ = 10 ⁻³ m ³
mass	metric ton	t	1 t = 10 ³ kg

^aUse discouraged except for special fields such as cartography.

^bSee 3.3.2.4.

Table 7
Units in Use with SI Temporarily

Quantity ³	Unit	Symbol	Definition
energy [See 3.3.3.1]	kilowatthour	kWh	1 kWh = 3.6 MJ
cross section	barn	b	1 b = 10 ⁻²⁸ m ²
pressure [See 3.3.3.2]	bar	bar	1 bar = 10 ⁵ Pa
activity (of a radionuclide)	curie	Ci	1 Ci = 3.7 × 10 ¹⁰ Bq
exposure (x and gamma rays)	roentgen	R	1 R = 2.58 × 10 ⁻⁴ C/kg
absorbed dose	rad	rd	1 rd = 0.01 Gy

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 metric ton of 1000 kg (also called the *tonne*). 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.

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 is applicable to all such measurements. (See also 3.4.6). Old metric gravitational units for pressure and stress such as kilogram-force

per square centimeter (kgf/cm^2) 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 is widely used in meteorology; this usage will continue for the present in order to permit meteorologists to communicate easily within their profession. 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) are to 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 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) are to 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 angstrom (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:

fermi	1 fermi	= 1 fm = 10^{-15} m
micron	1 micron	= 1 μm = 10^{-6} m
millimicron . . .	1 millimicron	= 1 nm = 10^{-9} m
are	1 are	= 1 dam ² = 100 m ²
gamma	1 gamma	= 1 nT
	(magnetic flux density)	
γ (mass)	1 γ	= 1 μg
λ (volume) . . .	1 λ	= 1 μL = 1 mm ³
mho	1 mho	= 1 S
candle	1 candle	= 1 cd
candlepower . .	1 candlepower	= 1 cd

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

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

3.4 Other Recommendations Concerning Units.

3.4.1 Mass, Force, and Weight.

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 (see Fig 1). Likewise, the newton rather than the kilogram-force is used to form derived units which include force, for example, pressure or stress ($\text{N}/\text{m}^2 = \text{Pa}$), energy ($\text{N}\cdot\text{m} = \text{J}$), and power ($\text{N}\cdot\text{m}/\text{s} = \text{W}$).

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% 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.

3.4.1.3 Gravity is involved in determining mass with a balance or scale. When a standard mass is used to balance the measured mass, the effects of gravity on the two masses are equalized, but the effects of the buoyancy of air or other fluid on the two masses are generally not equalized. When a spring scale is used, the scale reading is directly related to the force of gravity. Spring scales graduated in mass units may be properly used if both the variation in acceleration of gravity and the buoyancy corrections are not significant in their use.

3.4.1.4 The use of the same name for units of force and mass causes confusion. When non-SI units are used, a distinction should be made between *force* and *mass*, for example, lbf to denote force in gravimetric engineering units and lb for mass.

3.4.1.5 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. A load that produces a force from anything

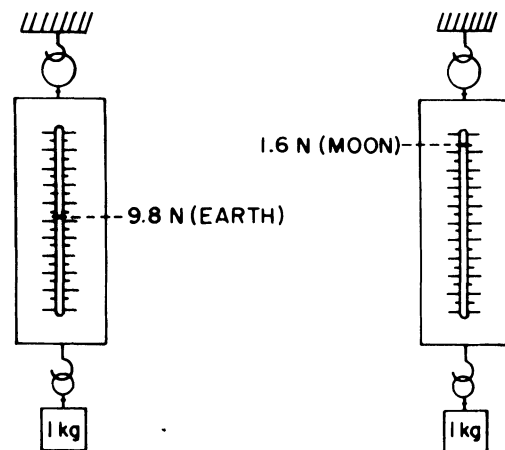


Fig 1
Illustration of Difference Between Mass
(Unit: Kilogram) and Force (Unit: Newton)

other than the influence of gravity is expressed in force units.

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 ($^{\circ}C$), 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 temperature work of extreme precision, the International Practical Temperature Scale (IPTS) must be recognized, because many available data are based upon it. This scale was agreed upon by the CIPM in 1968. The IPTS text was amended in 1975, and the scale was extended to lower temperatures by a supplementary scale, the EPT-76 (abbreviation for the French title: "Echelle Provisoire de Temperature de 1976 entre 0.5 K et 30 K"). These scales are based on certain "defining fixed points" that permit calibration of in-

struments. The assignments of temperatures to these fixed points were based on the best available determinations of their thermodynamic temperatures. The basis of the Practical Scale is given in Footnote 11 (see X1.12.5 of Appendix X1).

3.4.3. Linear Dimensions.

3.4.3.1 Nominal dimensions name the item; no SI equivalent is required (see Section 5 for definition of “nominal value”). For example, there is nothing “1 in” about a nominal “1-in pipe,” the dimensions of which should be converted as follows:

Nominal Size inches	Outside Diameter inches (mm)	Wall Thickness, inches (mm)		
		Sch 40	Sch 80	Sch 160
1	1.315 (33.40)	0.133 (3.38)	0.179 (4.55)	0.250 (6.35)

Likewise, a “2 by 4” is that in name only and refers to the approximate dimensions in inches of a rough-sawn piece of green lumber, the finished dimensions of which are considerably less. A .250-20 UNC screw thread should continue to be identified in this manner. However, the controlling dimensions of the part, such as the pitch, major, and minor diameters of a screw thread, should be converted to SI values in accordance with 4.1 and 4.2.

3.4.3.2 Surface finish should be expressed in micrometers.

3.4.4 Energy and Torque.

3.4.4.1 The vector product of force and moment arm is widely designated by the unit newton meter. This unit for bending moment or torque results in confusion with the unit for energy, which is also newton meter. If torque is expressed as newton meter per radian, the relationship to energy is clarified, since the product of torque and angular rotation is energy:

$$(\text{N} \cdot \text{m} / \text{rad}) \cdot \text{rad} = \text{N} \cdot \text{m}$$

3.4.4.2 If vectors were shown, the distinction between energy and torque would be obvious, since the orientation of force and length is different in the two cases. It is important to recognize this difference in us-

ing torque and energy, and the joule should never be used for torque.

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 Dimensionless Quantities:

3.4.7.1 The values of so-called dimensionless quantities, as for example refractive index and relative permeability, are expressed by pure numbers. In these cases the corresponding SI unit is the ratio of the same two SI units and may be expressed by the number 1.

3.4.7.2 Units such as percent, parts per thousand, and parts per million may also be used.

3.4.7.3 In all cases, the meaning must be unequivocal. Expressions like “The volume fraction of CO₂ in the sample was 1.2 parts per million” or “The mass fraction of CO₂ in the sample was 1.2 parts per million” 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. Care must be taken to use unit symbols properly, and international agreement provides uniform rules. Handling of unit names varies because of language differences, but use of the rules included here will improve communications in the United States.

3.5.1 Rules for Writing Unit Symbols.

3.5.1.1 Unit symbols should be printed in roman (upright) type regardless of the type style used in the surrounding text.

3.5.1.2 Unit symbols are unaltered in the plural.

3.5.1.3 Unit symbols are not followed by a period except when used at the end of a sentence.

3.5.1.4 Letter unit symbols are written in lower-case (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 lower-case or upper-case letters as shown in 2.5.1. Symbols retain their prescribed form regardless of the surrounding typography.⁷

3.5.1.5 When a quantity is expressed as a numerical value and a unit symbol, a space should 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 numerical value and the symbols for degree, minute, and second of plane angle.

3.5.1.6 When a quantity expressed as a numerical value and a unit is used in an adjectival sense, a hyphen is often used in lieu of a space between the number and the unit name or between the number and the symbol. Examples:

A three-meter pole A length of 3 m
A 35-mm film A width of 35 mm
However, per 3.5.1.5 Exception,
a 90° angle an angle of 90°.

3.5.1.7 No space is used between the prefix and unit symbols.

3.5.1.8 Symbols, not abbreviations, should be used for units. For example, use “A” and not “amp” for ampere.

3.5.2 Rules for Writing Names.

3.5.2.1 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.

⁷For symbols for use in systems with limited character sets, refer to ANSI X3.50-1976 or ANSI/IEEE Std 260-1978, as applicable. The symbols in ANSI X3.50-1976 are intended for applications in the field of information processing, where unambiguous transmission of information between computers is required. The symbols in ANSI/IEEE Std 260-1978 are generally consistent with those in ANSI X3.50-1976 and are intended for communication between human beings. The symbols for limited character sets must never be used when the available character set permits the use of the proper general-use symbols as given in this standard.

3.5.2.2 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

3.5.2.3 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.

3.5.2.4 The spellings *meter* and *liter* are recommended. This is in accordance with guidance given by the 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* and *litre* are also used, especially in British English.

3.5.3 Units Formed by Multiplication and Division.

3.5.3.1 With unit names:

Product, use a space (preferred) or hyphen:

newton meter *or* newton-meter

In the case of the watt hour the space may be omitted, thus:

watthour

Quotient, use the word *per* and not a solidus:

meter per second, *not* meter/second

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.