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Guide for the Use of the International System of Units (SI)

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Preface

The International System of Units was established in 1960 by the 11th the *Conférence Générale des Poids et Mesures* (CGPM). Universally abbreviated SI (from the French *Le Système International d'Unitès*). It is the modern metric system of measurement used throughout the world.

The purpose of this *Guide* is to provide a comprehensive reference for the use of SI units in the reports, theses and dissertations of the Department of Mechanical Engineering at the University of Stellenbosch. The authoritative specification for the use of SI units in South Africa is SABS M33a [1], which was enforced by the Government Notice R.1791 of 4 October 1974. This specification is unfortunately out of date with regards to the current official SI units and unit symbols as specified by the *Bureau International des Poids et Mesures* (BIPM). The material in sections 1 to 3 was therefore taken verbatim from the SI Brochure [2] and Supplement to the SI brochure [3].

This *Guide* also serves as a style guide for the use of SI units and decimal numbers. SABS M33a [1], unfortunately gives only a few examples for style of SI units and numbers and all the material in this guide was taken directly from the very comprehensive American Guide, NIST SP811 [4].

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The BIPM and the Convention du Mètre

The *Bureau International des Poids et Mesures* (BIPM) was set up by the *Convention du Mètre* signed in Paris on 20 May 1875 by seventeen[1] States during the final session of the diplomatic Conference of the Metre. This Convention was amended in 1921.

The task of the BIPM is to ensure world-wide unification of physical measurements; its function is thus to:

- establish fundamental standards and scales for the measurement of the principal physical quantities and maintain the international prototypes;
- carry out comparisons of national and international standards;
- ensure the coordination of corresponding measuring techniques;
- carry out and coordinate measurements of the fundamental physical constants relevant to these activities.

The BIPM operates under the exclusive supervision of the *Comité International des Poids et Mesures* (CIPM) which itself comes under the authority of the *Conférence Générale des Poids et Mesures* (CGPM) and reports to it on the work accomplished by the BIPM.

Delegates from all Member States of the *Convention du Mètre* attend the *Conférence Générale* which, at present, meets every four years. The function of these meetings is to :

- discuss and initiate the arrangements required to ensure the propagation and improvement of the International System of Units (SI), which is the modern form of the metric system;
- confirm the results of new fundamental metrological determinations and various scientific resolutions of international scope;
- take all major decisions concerning the finance, organization and development of the BIPM.

The Comité International has eighteen members each from a different State: at present, it meets every year. The officers of this committee present an Annual Report on the administrative and financial position of the BIPM to the Governments of the Member States of the *Convention du Mètre.* The principal task of the CIPM is to ensure world-wide uniformity in units of measurement. It does this by direct action or by submitting proposals to the CGPM.

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[1] As of 31 December 1997, forty-eight States were members of this Convention: Argentina, Australia, Austria, Belgium,Brazil, Bulgaria, Cameroon,Canada, Chile, China, Czech Republic, Denmark, Dominican Republic, Egypt, Finland, France, Germany, Hungary, India,Indonesia, Iran (Islamic Rep. of), Ireland, Israel, Italy, Japan, Korea (Dem. People's Rep. of), Korea (Rep. of),Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Portugal, Romania, Russian Federation, Singapore, Slovakia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, United States, Uruguay, Venezuela.

1 SI Units

SI units are divided into two classes:

- base units;
- derived units.

The CGPM decided to base the International System on a choice of seven well-defined units which by convention are regarded as dimensionally independent: the metre, the kilogram, the second, the ampere, the kelvin, the mole, and the candela. These SI units are called base units.

The second class of SI units is that of derived units. These are units that are formed as products of powers of the base units according to the algebraic relations linking the quantities concerned. The names and symbols of some units thus formed in terms of base units may be replaced by special names and symbols which can themselves be used to form expressions and symbols for other derived units.

The SI units of these two classes form a coherent set of units, where coherent is used in the specialist sense of a system whose units are mutually related by rules of multiplication and division with no numerical factor other than 1. The units of this coherent set of units are designated by the name SI units.

1.1 SI base units

Table 1 gives the seven base quantities, assumed to be mutually independent, on which the SI is founded; and the names and symbols of their respective units, called "SI base units." Definitions of the SI base units are given in Appendix A. The kelvin and its symbol K are also used to express the value of a temperature interval or a temperature difference.

1.1.1 Unit of length (metre)

The 1889 definition of the metre,[†] based upon the international prototype of platinum-iridium, was replaced by the 11th CGPM (1960) using a definition based upon a wavelength of krypton 86 radiation. This definition was adopted in order to improve the accuracy with which the metre may be realized. In turn, this was replaced in 1983 by the 17th CGPM (1984):

[†] The official spelling in South Africa is "metre", "litre" and "deca" as opposed to the American spelling of "meter", "liter" and "deka".

Table 1: SI base units

	SI base unit	
Base quantity	**Name**	**Symbol**
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

> *The metre is the length of the path travelled by light in vacuum during a time interval of* 1/299 792 458 *of a second.*

Note that this definition fixes the speed of light at exactly 299 792 458 $\mathrm{m{\cdot}s^{-1}}$. The original international prototype of the metre, which was sanctioned by the 1st CGPM in 1889, is still kept at the BIPM under conditions specified in 1889.

1.1.2 Unit of mass (kilogram)

The international prototype of the kilogram, made of platinum-iridium, is kept at the BIPM under conditions specified by the 1st CGPM in 1889 when it sanctioned the prototype and declared:

> *This prototype shall henceforth be considered to be the unit of mass.*

The 3rd CGPM (1901), in a declaration intended to end the ambiguity in popular usage concerning the word "weight" confirmed that:

> *The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.*

1.1.3 Unit of time (second)

The unit of time, the second, was at one time considered to be the fraction 1/86 400 of the mean solar day. The exact definition of "mean solar day" was based on astronomical theories. However, measurement showed that irregularities in the rotation of the Earth could not be taken into account by the theory and have the effect that this definition does not allow the required accuracy to be achieved. In order to define the unit of time more precisely, the 11th CGPM (1960) adopted a definition given by the International Astronomical Union which was based on the tropical year. Experimental work, however, had already shown that an atomic standard of time interval, based on a transition between two energy levels of an atom or a molecule, could be realized and reproduced much more precisely. Considering that a very precise definition of the unit of time is indispensable for the International System, the 13th CGPM (1967–1968) replaced the definition of the second by the following:

> *The second is the duration of* 9 192 631 770 *periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.*

At its 1997 meeting, the CIPM affirmed that:

> *This definition refers to a caesium atom in its ground state at a temperature of* 0 K.

This note was intended to make it clear that the definition of the SI second is based on a Cs atom unperturbed by black-body radiation, that is, in an environment whose temperature is 0 K, and that the frequencies of primary frequency standards should therefore be corrected for the shift due to ambient radiation, as stated at the meeting of the CCTF in 1999.

1.1.4 Unit of electric current (ampere)

Electric units, called “international”, for current and resistance were introduced by the International Electrical Congress held in Chicago in 1893, and definitions of the “international” ampere and the “international” ohm were confirmed by the International Conference of London in 1908.

Although it was already obvious on the occasion of the 8th CGPM (1933) that there was a unanimous desire to replace those “international” units by so-called “absolute” units, the official decision to abolish them was only taken by the 9th CGPM (1948), which adopted the ampere for the unit of electric current, following a definition proposed by the CIPM (1946):

> *The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed* $1\ \mathrm{m}$ *apart in vacuum, would produce between these conductors a force equal to* $2\times10^{-7}\ \mathrm{N/m}$ *of length.*

Note that the effect of this definition is to fix the permeability of vacuum at exactly $4\pi\times10^{-7}\,\mathrm{H{\cdot}m^{-1}}$.

1.1.5 Unit of thermodynamic temperature (kelvin)

The definition of the unit of thermodynamic temperature was given in substance by the 10th CGPM (1954) which selected the triple point of water as the fundamental fixed point and assigned to it the temperature 273,16 K so defining the unit. The 13th CGPM (1967–1968) adopted the name kelvin (symbol K) instead of “degree Kelvin” (symbol °K) and defined the unit of thermodynamic temperature as follows:

> *The kelvin, unit of thermodynamic temperature, is the fraction* $1/273{,}16$ *of the thermodynamic temperature of the triple point of water.*

Because of the way temperature scales used to be defined, it remains common practice to express a thermodynamic temperature, symbol T, in terms of its difference from the reference temperature[2] $T_0 = 273{,}15$ K, the ice point. This temperature difference is called the Celsius temperature, symbol t, and is defined by the quantity equation

$$t = T - T_0.$$

The unit of Celsius temperature is the degree Celsius, symbol °C, which is by definition equal in magnitude to the kelvin. A difference or interval of temperature may be expressed in kelvins or in degrees Celsius (13th CGPM, 1967–1968). The numerical value of a Celsius temperature t expressed in degrees Celsius is given by

$$t/{}^\circ\mathrm{C} = T/\mathrm{K} - 273{,}15.$$

The kelvin and the degree Celsius are also the units of the International Temperature Scale of 1990 (ITS-90) adopted by the CIPM in 1989.

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[2] Note that the thermodynamic reference temperature T_0 is exactly 0,01 K below the thermodynamic temperature of the triple point of water.

1.1.6 Unit of amount of substance (mole)

Following the discovery of the fundamental laws of chemistry, units called, for example, “gram-atom” and “gram-molecule”, were used to specify amounts of chemical elements or compounds. These units had a direct connection with “atomic weights” and “molecular weights”, which are in fact relative masses. “Atomic weights” were originally referred to the atomic weight of oxygen, by general agreement taken as 16. But whereas physicists separated isotopes in the mass spectrometer and attributed the value 16 to one of the isotopes of oxygen, chemists attributed that same value to the (slightly variable) mixture of isotopes 16, 17 and 18, which was for them the naturally occurring element oxygen. Finally, an agreement between the International Union of Pure and Applied Physics (IUPAP) and the International Union of Pure and Applied Chemistry (IUPAC) brought this duality to an end in 1959/60. Physicists and chemists have ever since agreed to assign the value 12, exactly, to the “atomic weight”, correctly the relative atomic mass, of the isotope of carbon with mass number 12 (carbon 12, ^{12}C). The unified scale thus obtained gives values of relative atomic mass.

It remained to define the unit of amount of substance by fixing the corresponding mass of carbon 12; by international agreement this mass was fixed at 0,012 kg, and the unit of the quantity “amount of substance” was given the name mole (symbol mol).

Following proposals by the IUPAP, the IUPAC and the ISO, the CIPM gave a definition of the mole in 1967 and confirmed it in 1969: this was adopted by the 14th CGPM (1971):

1. *The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in* 0,012 kg *of carbon 12; its symbol is* “mol”.
2. *When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.*

In 1980 the CIPM approved the report of the CCU (1980) which specified that:

> *In this definition, it is understood that unbound atoms of carbon 12, at rest and in their ground state, are referred to.*

1.1.7 Unit of luminous intensity (candela)

The units of luminous intensity based on flame or incandescent filament standards in use in various countries before 1948 were replaced initially by the “new candle” based on the luminance of a Planckian radiator (a black body) at the temperature of freezing platinum. This modification had been prepared by the International Commission on Illumination (CIE) and by the CIPM before 1937 and the decision was promulgated by the CIPM in 1946. It was then ratified in 1948 by the 9th CGPM which adopted a new international name for this unit, the candela (symbol cd); in 1967 the 13th CGPM (1967–1968) gave an amended version of the 1946 definition.

In 1979, because of the experimental difficulties in realizing a Planck radiator at high temperatures and the new possibilities offered by radiometry, i.e. the measurement of optical radiation power, the 16th CGPM (1979) adopted a new definition of the candela:

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz *and that has a radiant intensity in that direction of* 1/683 *watt per steradian.*

1.2 SI derived units

Derived units are units which may be expressed in terms of base units by means of the mathematical symbols of multiplication and division. Certain derived units have been given special names and symbols, and these special names and symbols may themselves be used in combination with those for base and other derived units to express the units of other quantities.

Table 2: SI Examples of SI derived units expressed in terms of base units

	SI derived unit	
Derived quantity	**Name**	**Symbol**
area	square metre	m^2
volume	cubic metre	m^3
speed,	velocity metre per second	m/s
acceleration	metre per second squared	m/s^2
wavenumber	reciprocal metre	m^{-1}
density, mass density	kilogram per cubic metre	kg/m^3
specific volume	cubic metre per kilogram	m^3/kg
current density	ampere per square metre	A/m^2
magnetic field strength	ampere per metre	A/m
concentration (of amount of substance)	mole per cubic metre	mol/m^3
luminance	candela per square metre	cd/m^2
refractive index	(the number) one	1[(a)]

[(a)] The symbol “1” is generally omitted in combination with a numerical value.

1.2.1 Units expressed in terms of base units

Table 2 lists some examples of derived units expressed directly in terms of base units. The derived units are obtained by multiplication and division of base units.

1.2.2 Units with special names and symbols; units which incorporate units with special names and symbols

For convenience, certain derived units, which are listed in table 3, have been given special names and symbols. These names and symbols may themselves be used to express other derived units: Table 4 shows some examples. The special names and symbols are a compact form for the expression of units which are used frequently. Consider, for example, the quantity molar entropy: the unit J/(mol·K) is obviously more easily understood than its SI base-unit equivalent, $m^2\cdot kg\cdot s^{-2}\cdot K^{-1}\cdot mol^{-1}$.

Table 3: SI derived units with special names and symbols

	SI derived unit			
Derived quantity	**Name**	**Symbol**	**Expressed in terms of other SI units**	**Expressed in terms of SI base units**
plane angle	radian(a)	rad		$\mathrm{m \cdot m^{-1}} = 1$(b)
solid angle	steradian(a)	sr(c)		$\mathrm{m^{2} \cdot m^{-2}} = 1$(b)
frequency	hertz	Hz		$\mathrm{s^{-1}}$
force	newton	N		$\mathrm{m \cdot kg \cdot s^{-2}}$
pressure, stress	pascal	Pa	$\mathrm{N/m^{2}}$	$\mathrm{m^{-1} \cdot kg \cdot s^{-2}}$
energy, work, quantity of heat	joule	J	$\mathrm{N \cdot m}$	$\mathrm{m^{2} \cdot kg \cdot s^{-2}}$
power, radiant flux	watt	W	$\mathrm{J/s}$	$\mathrm{m^{2} \cdot kg \cdot s^{-3}}$
electric charge, quantity of electricity	coulomb	C		$\mathrm{s \cdot A}$
electric potential difference, electromotive force	volt	V	$\mathrm{W/A}$	$\mathrm{m^{2} \cdot kg \cdot s^{-3} \cdot A^{-1}}$
capacitance	farad	F	$\mathrm{C/V}$	$\mathrm{m^{-2} \cdot kg^{-1} \cdot s^{4} \cdot A^{2}}$
electric resistance	ohm	Ω	$\mathrm{V/A}$	$\mathrm{m^{2} \cdot kg \cdot s^{-3} \cdot A^{-2}}$
electric conductance	siemens	S	$\mathrm{A/V}$	$\mathrm{m^{-2} \cdot kg^{-1} \cdot s^{3} \cdot A^{2}}$
magnetic flux	weber	Wb	$\mathrm{V \cdot s}$	$\mathrm{m^{2} \cdot kg \cdot s^{-2} \cdot A^{-1}}$
magnetic flux density	tesla	T	$\mathrm{Wb/m^{2}}$	$\mathrm{kg \cdot s^{-2} \cdot A^{-1}}$
inductance	henry	H	$\mathrm{Wb/A}$	$\mathrm{m^{2} \cdot kg \cdot s^{-2} \cdot A^{-2}}$
Celsius temperature	degree Celsius(d)	°C		K
luminous flux	lumen	lm	$\mathrm{cd \cdot sr}$(c)	$\mathrm{m^{2} \cdot m^{-2} \cdot cd = cd}$
illuminance	lux	lx	$\mathrm{lm/m^{2}}$	$\mathrm{m^{2} \cdot m^{-4} \cdot cd = m^{-2} \cdot cd}$
activity (referred to a radionuclide)	becquerel	Bq		$\mathrm{s^{-1}}$
absorbed dose, specific energy (imparted), kerma	gray	Gy	$\mathrm{J/kg}$	$\mathrm{m^{2} \cdot s^{-2}}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent, organ equivalent dose	sievert	Sv	$\mathrm{J/kg}$	$\mathrm{m^{2} \cdot s^{-2}}$
catalytic activity	katal	kat		$\mathrm{s^{-1} \cdot mol}$

(a) The radian and steradian may be used with advantage in expressions for derived units to distinguish between quantities of different nature but the same dimension. Some examples of their use in forming derived units are given in table 3.

(b) In practice, the symbols rad and sr are used where appropriate, but the derived unit “1” is generally omitted in combination with a numerical value.

(c) In photometry, the name steradian and the symbol sr are usually retained in expressions for units.

(d) This unit may be used in combination with SI prefixes, e.g. millidegree Celsius, m°C.

Table 4: Examples of SI derived units whose names and symbols include SI derived units with special names and symbols

	SI derived unit		
Derived quantity	**Name**	**Symbol**	**Expressed in terms of SI base units**
dynamic viscosity	pascal second	$\mathrm{Pa\cdot s}$	$\mathrm{m^{-1}\cdot kg\cdot s^{-1}}$
moment of force	newton metre	$\mathrm{N\cdot m}$	$\mathrm{m^{2}\cdot kg\cdot s^{-2}}$
surface tension	newton per metre	$\mathrm{N/m}$	$\mathrm{kg\cdot s^{-2}}$
angular velocity	radian per second	$\mathrm{rad/s}$	$\mathrm{m\cdot m^{-1}\cdot s^{-1} = s^{-1}}$
angular acceleration	radian per second squared	$\mathrm{rad/s^{2}}$	$\mathrm{m\cdot m^{-1}\cdot s^{-2} = s^{-2}}$
heat flux density, irradiance	watt per square metre	$\mathrm{W/m^{2}}$	$\mathrm{kg\cdot s^{-3}}$
heat capacity, entropy	joule per kelvin	$\mathrm{J/K}$	$\mathrm{m^{2}\cdot kg\cdot s^{-2}\cdot K^{-1}}$
specific heat capacity, specific entropy	joule per kilogram kelvin	$\mathrm{J/(kg\cdot K)}$	$\mathrm{m^{2}\cdot s^{-2}\cdot K^{-1}}$
specific energy	joule per kilogram	$\mathrm{J/kg}$	$\mathrm{m^{2}\cdot s^{-2}}$
thermal conductivity	watt per metre kelvin	$\mathrm{W/(m\cdot K)}$	$\mathrm{m\cdot kg\cdot s^{-3}\cdot K^{-1}}$
energy density	joule per cubic metre	$\mathrm{J/m^{3}}$	$\mathrm{m^{-1}\cdot kg\cdot s^{-2}}$
electric field strength	volt per metre	$\mathrm{V/m}$	$\mathrm{m\cdot kg\cdot s^{-3}\cdot A^{-1}}$
electric charge density	coulomb per cubic metre	$\mathrm{C/m^{3}}$	$\mathrm{m^{-3}\cdot s\cdot A}$
electric flux density	coulomb per square metre	$\mathrm{C/m^{2}}$	$\mathrm{m^{-2}\cdot s\cdot A}$
permittivity	farad per metre	$\mathrm{F/m}$	$\mathrm{m^{-3}\cdot kg^{-1}\cdot s^{4}\cdot A^{2}}$
permeability	henry per metre	$\mathrm{H/m}$	$\mathrm{m\cdot kg\cdot s^{-2}\cdot A^{-2}}$
molar energy	joule per mole	$\mathrm{J/mol}$	$\mathrm{m^{2}\cdot kg\cdot s^{-2}\cdot mol^{-1}}$
molar entropy, molar heat capacity	joule per mole kelvin	$\mathrm{J/(mol\cdot K)}$	$\mathrm{m^{2}\cdot kg\cdot s^{-2}}$
exposure (x and γ rays)	coulomb per kilogram	$\mathrm{C/kg}$	$\mathrm{kg^{-1}\cdot s\cdot A}$
absorbed dose rate	gray per second	$\mathrm{Gy/s}$	$\mathrm{m^{2}\cdot s^{-3}}$
radiant intensity	watt per steradian	$\mathrm{W/sr}$	$\mathrm{m^{4}\cdot m^{-2}\cdot kg\cdot s^{-3} = m^{2}\cdot kg\cdot s^{-3}}$
radiance	watt per square metre steradian	$\mathrm{W/(m^{2}\cdot sr)}$	$\mathrm{m^{2}\cdot m^{-2}\cdot kg\cdot s^{-3} = kg\cdot s^{-3}}$
catalytic (activity) concentration	katal per cube metre	$\mathrm{kat/m^{3}}$	$\mathrm{m^{-1}\cdot s^{-1}\cdot mol}$

In tables 3 and 4, the final column shows how the SI units concerned may be expressed in terms of SI base units. In this column, factors such as m^0, kg^0 ..., which are all equal to 1, are not shown explicitly.

A single SI unit may correspond to several different quantities. In table 4 on the preceding page there are several examples. Thus the joule per kelvin (J/K) is the SI unit for the quantity heat capacity as well as for the quantity entropy. It is therefore important not to use the unit alone to specify the quantity. This rule applies not only to scientific and technical texts but also, for example, to measuring instruments (i.e. an instrument should indicate both the unit and the quantity measured).

A derived unit can often be expressed in several different ways through the use of base units and derived units with special names. In practice, with certain quantities, preference is given to using certain units with special names, or combinations of units, to facilitate the distinction between quantities whose values have identical expressions in terms of SI base units. For example, the SI unit of frequency is specified as the hertz (Hz) rather than the reciprocal second (s^{-1}), and the SI unit of angular velocity is designated the radian per second (rad/s) rather than the reciprocal second (in this case retaining the word radian emphasizes that angular velocity is equal to 2π times the rotational frequency). Similarly the SI unit of moment of force is specified as the newton metre (N·m) rather than the joule (J).

1.2.3 Units for dimensionless quantities, quantities of dimension one

Certain quantities are defined as the ratios of two quantities of the same kind, and thus have a dimension which may be expressed by the number one. The unit of such quantities is necessarily a derived unit coherent with the other units of the SI and, since it is formed as the ratio of two identical SI units, the unit also may be expressed by the number one. Thus the SI unit of all quantities having the dimensional product one is the number one. Examples of such quantities are refractive index, relative permeability, and friction factor. Other quantities having the unit 1 include "characteristic numbers" like the Prandtl number $\eta c_p/\lambda$ and numbers which represent a count, such as a number of molecules, degeneracy (number of energy levels) and partition function in statistical thermodynamics. All of these quantities are described as being dimensionless, or of dimension one, and have the coherent SI unit 1. Their values are simply expressed as numbers and, in general, the unit 1 is not explicitly shown. In a few cases, however, a special name is given to this unit, mainly to avoid confusion between some compound derived units. This is the case for the radian, steradian and neper.

2 Prefixes

2.1 Decimal multiples and submultiples of SI units

Table 5 gives the SI prefixes that are used to form decimal multiples and submultiples of SI units. A prefix attaches directly to the name of a unit, and a prefix symbol attaches directly to the symbol for a unit. For example, one kilometre, symbol 1 km, is equal to one thousand metres, symbol 1000 m or 10^3 m. When prefixes are attached to SI units, the units so formed are called “multiples and submultiples of SI units” in order to distinguish them from the coherent system of SI units.

Table 5: SI prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
$10^{24} = (10^3)^8$	yotta	Y	10^{-1}	deci	d
$10^{21} = (10^3)^7$	zetta	Z	10^{-2}	centi	c
$10^{18} = (10^3)^6$	exa	E	$10^{-3} = (10^3)^{-1}$	milli	m
$10^{15} = (10^3)^5$	peta	P	$10^{-6} = (10^3)^{-2}$	micro	µ
$10^{12} = (10^3)^4$	tera	T	$10^{-9} = (10^3)^{-3}$	nano	n
$10^{9} = (10^3)^3$	giga	G	$10^{-12} = (10^3)^{-4}$	pico	p
$10^{6} = (10^3)^2$	mega	M	$10^{-15} = (10^3)^{-5}$	femto	f
$10^{3} = (10^3)^1$	kilo	k	$10^{-18} = (10^3)^{-6}$	atto	a
10^{2}	hecto	h	$10^{-21} = (10^3)^{-7}$	zepto	z
10^{1}	deca	da	$10^{-24} = (10^3)^{-8}$	yocto	y

Kilogram

Among the base units of the International System, the unit of mass is the only one whose name, for historical reasons, contains a prefix. Names and symbols for decimal multiples and submultiples of the unit of mass are formed by attaching prefix names to the unit name “gram” and prefix symbols to the unit symbol “g”.

Example: 10^{-6} kg = 1 mg (1 milligram) *but not* 1 µkg (1 microkilogram)

2.2 Prefixes for binary multiples (non-SI)

In December 1998 the International Electrotechnical Commission (IEC), the leading international organization for worldwide standardization in electrotechnology, approved as an IEC International Standard (IEC 60027-2 [7]), names and symbols for prefixes for binary multiples for use in the fields of data processing and data transmission. The prefixes are as shown in table 6 on the next page.

It is important to recognize that the new prefixes for binary multiples are *not* part of the International System of Units (SI), the modern metric system. However, for ease of understanding and recall, they were derived from the SI prefixes for positive powers of ten. As can be seen from table 6, the name of each new prefix is derived from the name of the corresponding SI prefix by retaining the first two letters of the name of the SI prefix and adding the letters “bi", which

Table 6: Prefixes for binary multiples

Factor	Name	Prefix	Symbol
$2^{10} = (2^{10})^1$	kilobinary:	kibi	Ki
$2^{20} = (2^{10})^2$	megabinary:	mebi	Mi
$2^{30} = (2^{10})^3$	gigabinary:	gibi	Gi
$2^{40} = (2^{10})^4$	terabinary:	tebi	Ti
$2^{50} = (2^{10})^5$	petabinary:	pebi	Pi
$2^{60} = (2^{10})^6$	exabinary:	exbi	Ei

recalls the word “binary". Similarly, the symbol of each new prefix is derived from the symbol of the corresponding SI prefix by adding the letter “i", which again recalls the word “binary". (For consistency with the other prefixes for binary multiples, the symbol Ki is used for 2^{10} rather than ki.)

Examples: one kibibyte: 1 KiB $= (2^{10})^1$ B $=$ 1024 B

one mebibyte: 1 MiB $= (2^{10})^2$ B $=$ 1 048 576 B

one gibibyte: 1 GiB $= (2^{10})^3$ B $=$ 1 073 741 824 B

one kilobyte: 1 kB $= (10^3)^1$ B $=$ 1000 B

one megabyte: 1 MB $= (10^3)^2$ B $=$ 1 000 000 B

one gigabyte: 1 GB $= (10^3)^3$ B $=$ 1 000 000 000 B

3 Units outside the SI

SI units are recommended for use throughout science, technology and commerce. They are agreed internationally by the CGPM, and provide the reference in terms of which all other units are now defined. The SI base units and SI derived units, including those with special names, have the important advantage of forming a coherent set with the effect that unit conversions are not required when inserting particular values for quantities in quantity equations.

Nonetheless it is recognized that some non-SI units still appear widely in the scientific, technical and commercial literature, and some will probably continue to be used for many years. Other non-SI units, such as the units of time, are so widely used in everyday life, and are so deeply embedded in the history and culture of the human race, that they will continue to be used for the foreseable future. For these reasons some of the more important non-SI units are listed in the tables below.

The inclusion of tables of non-SI units in this text does not imply that the use of non-SI units is to be encouraged. With a few exceptions discussed below, SI units are always to be preferred to non-SI units. It is desirable to avoid combining non-SI units with units of the SI; in particular the combination of such units with SI units to form compound units should be restricted to special cases so as to retain the advantage of coherence conferred by the use of SI units.

3.1 Units used with the SI

The CIPM (1969), recognizing that users would wish to employ the SI with units which are not part of it but are important and widely used, listed three categories of non-SI units: units to be maintained; to be tolerated temporarily; and to be avoided. In reviewing this categorization the CIPM (1996) agreed a new classification of non-SI units: units accepted for use with the SI, table 7; units accepted for use with the SI whose values are obtained experimentally, table 8; and other units currently accepted for use with the SI to satisfy the needs of special interests, table 9. Table 7 lists non-SI units which are accepted for use with the SI. It includes units which are in continuous everyday use, in particular the traditional units of time and of angle, together with a few other units which have assumed increasing technical importance.

Table 8 lists three non-SI units which are also accepted for use with the SI, whose values expressed in SI units must be obtained by experiment and are therefore not known exactly. Their values are given with their combined standard uncertainties (coverage factor $k = 1$), which apply to the last two digits, shown in parentheses. These units are in common use in certain specialized fields.

Table 9 lists some other non-SI units which are currently accepted for use with the SI to satisfy the needs of commercial, legal and specialized scientific interests. These units should be defined in relation to the SI in every document in which they are used. Their use is not encouraged.

Table 7: Non-SI units accepted for use with the International System

Name		Symbol	Value in SI units
minute	time	min	1 min = 60 s
hour		h	1 h = 60 min = 3600 s
day		d	1 d = 24 h = 86 400 s
degree	plane angles(a)	°	1° = (π/180) rad
minute		′	1′ = (1/60)° = (π/10 800) rad
second		″	1″ = (1/60)′ = (π/648 000) rad
litre(b)		L, l(c)	$1\ \mathrm{L} = 1\ \mathrm{dm}^3 = 10^{-3}\ \mathrm{m}^3$
ton (metric)(d)		t	$1\ \mathrm{t} = 10^3\ \mathrm{kg}$
neper(e, g)		Np	1 Np = 1
bel(f, g)		B	1 B = (1/2) ln 10 (Np)(h)

(a) ISO 31 [5] recommends that the degree be subdivided decimally rather than using the minute and second. See also section 5.1.7.

(b) Note that the litre is a "commercial" unit and is intended for everyday use and not for scientific calculations, because it is not consistent with other SI units. See also section 5.2.8.

(c) The symbol, L, was adopted by the 16th CGPM (1979) in order to avoid the risk of confusion between the letter l and the number 1. The script letter ℓ is not an approved symbol for the litre, but is widely used in South Africa and is recognized as such in SABS M33a [1] as the preferred symbol in South Africa.

(d) The metric ton is likewise a "commercial" unit and is intended for everyday use and not for scientific calculations. Only the SI prefixes kilo-, mega-, giga-, peta-, and exa- may be used with the metric ton. It is also called "tonne" in many countries.

(e) The neper is used to express values of such logarithmic quantities as field level, power level, sound pressure level, and logarithmic decrement. Natural logarithms are used to obtain the numerical values of quantities expressed in nepers. The neper is coherent with the SI, but not yet adopted by the CGPM as an SI unit. For further information see International Standard ISO 31 [5].

(f) The bel is used to express values of such logarithmic quantities as field level, power level, sound pressure level, and attenuation. Logarithms to base ten are used to obtain the numerical values of quantities expressed in bels. The submultiple decibel, dB, is commonly used. For further information see International Standard ISO 31 [5].

(g) In using these units it is particularly important that the quantity be specified. The unit must not be used to imply the quantity.

(h) Np is enclosed in parentheses because, although the neper is coherent with the SI, it has not yet been adopted by the CGPM.

Table 8: Non-SI units accepted for use with the International System, whose values in SI units are obtained experimentally

Name	Symbol	Value in SI units
electronvolt$^{(a)}$	eV	1 eV = $1{,}602\,177\,33(49)\times10^{-19}$ J
unified atomic mass unit$^{(b)}$	u	1 u = $1{,}660\,540\,2(10)\times10^{-27}$ kg
astronomical unit$^{(c)}$	ua	1 ua = $1{,}495\,978\,706\,91(30)\times10^{11}$ m

(a) The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum.

(b) The unified atomic mass unit is equal to 1/12 of the mass of an unbound atom of the nuclide ^{12}C, at rest, and in its ground state. In the field of biochemistry, the unified atomic mass unit is also called the dalton, symbol Da.

(c) The astronomical unit is a unit of length approximatively equal to the mean Earth-Sun distance. Its value is such that, when used to describe the motion of bodies in the Solar System, the heliocentric gravitational constant is $(0{,}017\,202\,098\,95)^2\ \text{ua}^3\cdot\text{d}^{-2}$.

Table 9: Other non-SI units currently accepted for use with the International System

Name	Symbol	Value in SI units
nautical mile$^{(a)}$		1 nautical mile = 1852 m
knot		1 nautical mile per hour = (1852/3600) m/s
are$^{(b)}$	a	1 a = 1 dam^2 = 10^2 m^2
hectare$^{(b)}$	ha	1 ha = 1 hm^2 = 10^4 m^2
bar	bar	1 bar = 0,1 MPa = 100 kPa = 1000 hPa = 10^5 Pa
ångström	Å	1 Å = 0,1 nm = 10^{-10} m
barn$^{(c)}$	b	1 b = 100 fm^2 = 10^{-28} m^2

(a) The nautical mile is a special unit employed for marine and aerial navigation to express distance. The conventional value given above was adopted by the First International Extraordinary Hydrographic Conference, Monaco, 1929, under the name “International nautical mile.” As yet there is no internationally agreed symbol. This unit was originally chosen because one nautical mile on the surface of the Earth subtends approximately one minute of angle at the centre.

(b) The units are and hectare and their symbols were adopted by the CIPM in 1879 and are used to express areas of land.

(c) The barn is a special unit employed in nuclear physics to express effective cross-sections.

3.2 Other non-SI units

Certain other non-SI units are still occasionally used. Some are important for the interpretation of older scientific texts. These are listed in Tables 9 and 10, but their use is not encouraged.

Table 10 deals with the relationship between CGS units and the SI, and lists those CGS units that were assigned special names. In the field of mechanics, the CGS system of units was built upon three quantities and the corresponding base units: the centimetre, the gram and the second. In the field of electricity and magnetism, units were expressed in terms of these three base units. Because this can be done in different ways, it led to the establishment of several different systems, for example the CGS Electrostatic System, the CGS Electromagnetic System and the CGS Gaussian System. In these three last-mentioned systems, the system of quantities and the corresponding system of equations differ from those used with SI units.

Table 11 lists units which are common in older texts. For current texts, it should be noted that if these units are used the advantages of the SI are lost. The relation of these units to the SI should be specified in every document in which they are used.

Table 10: Derived CGS units with special names

Name	Symbol	Value in SI units
erg	erg	1 erg = 10^{-7} J
dyne	dyn	1 dyn = 10^{-5} N
poise	P	1 P = 1 dyn·s/cm^2 = 0,1 Pa·s
stokes	St	1 St = 1 cm^2/s = 10^{-4} m^2/s
gauss(a)	G	1 G corresponds to 10^{-4} T
oersted(a)	Oe	1 Oe corresponds to (1000/4π) A/m
maxwell(a)	Mx	1 Mx corresponds to 10^{-8} Wb
stilb	sb	1 sb = 1 cd/cm^2 = 10^4 cd/m^2
phot	ph	1 ph = 10^4 lx
gal(b)	Gal	1 Gal = 1 cm/s^2 = 10^{-2} m/s^2

(a) This unit is part of the so-called “electromagnetic” three-dimensional CGS system and cannot strictly be compared with the corresponding unit of the International System, which has four dimensions when only mechanical and electric quantities are considered.

(b) The gal is a special unit employed in geodesy and geophysics to express acceleration due to gravity.

Table 11: Examples of other non-SI units

Name	Symbol	Value in SI units
curie(a)	Ci	1 Ci = $3{,}7\times10^{10}$ Bq
röntgen(b)	R	1 R = $2{,}58\times10^{-4}$ C/kg
rad(c,f)	rad	1 rad = 1 cGy = 10^{-2} Gy
rem(d,f)	rem	1 rem = 1 cSv = 10^{-2} Sv
X unit(e)		1 X unit ≈ $1{,}002\times10^{-4}$ nm
gamma(f)	γ	1 γ = 1 nT = 10^{-9} T
jansky	Jy	1 Jy = 10^{-26} $\mathrm{W \cdot m^{-2} \cdot Hz^{-1}}$
fermi(f)		1 fermi = 1 fm = 10^{-15} m
metric carat(g)		1 metric carat = 200 mg = 2×10^{-4} kg
torr	Torr	1 Torr = (101 325/760) Pa
standard atmosphere	atm(h)	1 atm = 101 325 Pa
calorie cal		(i)
micron(f)	μ(j)	1 μ = 1 μm = 10^{-6} m

(a) The curie is a special unit employed in nuclear physics to express activity of radionuclides.

(b) The röntgen is a special unit employed to express exposure to x or γ radiation.

(c) The rad is a special unit employed to express absorbed dose of ionizing radiation. When there is risk of confusion with the symbol for radian, rd may be used as the symbol for rad.

(d) The rem is a special unit used in radioprotection to express dose equivalent.

(e) The X unit was employed to express the wavelengths of x rays. Its relationship with the SI unit is an approximate one.

(f) Note that this non-SI unit is exactly equivalent to an SI unit with an appropriate submultiple prefix.

(g) The metric carat was adopted by the 4th CGPM in 1907 for commercial dealings in diamonds, pearls and precious stones.

(h) Resolution 4 of the 10th CGPM (1954). The designation "standard atmosphere" for a reference pressure of 101 325 Pa is still acceptable.

(i) Several "calories" have been in use:

- a calorie labelled "at 15 °C": 1 cal_{15} = 4,1855 J;
- a calorie labelled "IT" (International Table): 1 $\mathrm{cal}_{\mathrm{IT}}$ = 4,1868 J (5th International Conference on the Properties of Steam, London, 1956);
- a calorie labelled "thermochemical": 1 $\mathrm{cal}_{\mathrm{th}}$ = 4,184 J.

(j) The micron and its symbol, adopted by the CIPM in 1879 and repeated in Resolution 7 of the 9th CGPM (1948), were abolished by the 13th CGPM (1967–1968).

4 Notation for Numbers

4.1 Decimal sign or marker

With the publication of *South African Government Notice R.1146* on 5 June 1974 the ***comma*** became the only recognized decimal indicator in South Africa for all numbers, including amounts of money. For numbers smaller than 1 a zero *must* precede the decimal indicator.

Examples:	15,7 or R22,75	*but not*	15.7 or R22.75
	0,25 s	*but not*	,25 s

4.2 Grouping of digits

Digits should be separated into groups of three, counting from the decimal marker towards the left and right, by the use of a thin, fixed space. However, this practice is not usually followed for numbers having only four digits[†] on either side of the decimal marker except when uniformity in a table is desired. The point or (dot on the line) should not be used to separate digits into groups of three.

Examples:	76 483 522	*but not:*	76.483.522
	43 279,168 29	*but not:*	43.279,168 29
	8012 or 8 012	*but not:*	8.012
	0,491 722 3	*is preferred to:*	0,4917223
	0,5947 or 0,594 7	*but not:*	0,59 47
	8012,5947 or 8 012,594 7	*but not:*	8 012,5947 or 8012,594 7

Note: The practice of using a space to group digits is not usually followed in certain specialized applications, such as engineering drawings and financial statements.

4.3 Multiplying numbers

The preferred sign for the multiplication of numbers or values of quantities in South Africa is a cross (multiplication sign) (×) and not a half-high dot (·). This includes the writing of numbers in powers of ten.

Examples:	$13{,}247\,63 \times 10^{-3}$	*but not:*	$13{,}247\,63 \cdot 10^{-3}$
	53 m/s × 10,2 s	*but not:*	53 m/s · 10,2 s
	25 × 60,5	*but not:*	25 · 60,5

Note: The multiplication of quantity symbols (or numbers in parentheses or values of quantities in parentheses) may be indicated in one of the following ways: ab, $a\cdot b$, $a\times b$ or (12)(15).

[†] SABS M33a [1] recommends that number should always be separated into groups of three.

5 Rules and Style Conventions for Printing and Using Units

5.1 Rules and style conventions for unit symbols

The following sections give rules and style conventions related to the symbols for units.

5.1.1 Typeface

Unit symbols are printed in roman (upright) type regardless of the type used in the surrounding text.

Example: ***A moment of*** 10 N·m ***was applied.***

5.1.2 Capitalization

Unit symbols are printed in lower-case letters except that:

(a) the symbol or the first letter of the symbol is an upper-case letter when the name of the unit is derived from the name of a person; and

(b) the recommended symbol for the litre[†] is L (see table 7, footnote (b)).

Examples:	m (metre)	s (second)	V (volt)
	Pa (pascal)	lm (lumen)	Wb (weber)

5.1.3 Plurals

Unit symbols are unaltered in the plural.

Example: $l = 75$ cm *but not:* $l = 75$ cms

Note: l is the quantity symbol for length. (The rules and style conventions for expressing the values of quantities are discussed in detail in section 6.)

5.1.4 Punctuation

Unit symbols are not followed by a period unless at the end of a sentence.[‡]

Example: "Its length is 75 cm."
or: "It is 75 cm long." *but not:* "It is 75 cm. long."

5.1.5 Unit symbols obtained by multiplication

Symbols for units formed from other units by multiplication are indicated by means of either a half-high (that is, centered) dot or a space.[*] However, the half-high dot is preferred because it is less likely to lead to confusion.

Example: N m or N·m

Notes: 1. A half-high dot or space is usually imperative. For example, m·s^{-1} is the symbol for the metre per second while ms^{-1} is the symbol for the reciprocal millisecond, 10^3 s^{-1} (see section 5.2.3).

[†] SABS M33a [1] recommends the script ell, ℓ, but this is not a recognized SI symbol.

[‡] SABS M33a [1] recommends a space between the unit and the period: "Its length is 75 cm ."

[*] SABS M33a [1] also allows a period on the baseline, e.g.: N.m, but this is not recognized by the BIPM or ISO.

2. ISO 31 [5] suggests that if a space is used to indicate units formed by multiplication, the space may be omitted if it does not cause confusion. This possibility is reflected in the common practice of using the symbol kWh rather than kW·h or kW h for the kilowatt hour. Nevertheless, the position is taken that a half-high dot or a space should always be used to avoid possible confusion; and that for this same reason, only one of these two allowed forms should be used in any given manuscript.

5.1.6 Unit symbols obtained by division

Symbols for units formed from other units by division are indicated by means of a solidus (oblique stroke, /), a horizontal line, or negative exponents.

Example: $\mathrm{m/s}$, $\dfrac{\mathrm{m}}{\mathrm{s}}$, or $\mathrm{m{\cdot}s^{-1}}$

However, to avoid ambiguity, the solidus must not be repeated on the same line unless parentheses are used. Negative exponents should be used in complicated cases.

Examples: $\mathrm{m/s^2}$ or $\mathrm{m{\cdot}s^{-2}}$ *but not:* $\mathrm{m/s/s}$
$\mathrm{m{\cdot}kg/(s^3{\cdot}A)}$ or $\mathrm{m{\cdot}kg{\cdot}s^{-3}{\cdot}A^{-1}}$ *but not:* $\mathrm{m{\cdot}kg/s^3/A}$

5.1.7 Space between numerical value and unit symbol

In the expression for the value of a quantity, the unit symbol is placed after the numerical value and a *space* is left between the numerical value and the unit symbol.

Example: $9{,}81\ \mathrm{m/s^2}$ *but not:* $9{,}81\mathrm{m/s^2}$

The only exceptions to this rule are for the unit symbols for degree, minute, and second for plane angles: °, ′, and ″, respectively (see table 7), in which case no space is left between the numerical value and the unit symbol.

Example: $\alpha = 30°22'8''$

This rule means that:

1. The symbol °C for the degree Celsius is preceded by a space when one expresses the values of Celsius temperatures.

   Example: $t = 30{,}2\ °\mathrm{C}$ *but not:* $t = 30{,}2°\mathrm{C}$ or $t = 30{,}28°\ \mathrm{C}$

2. Even when the value of a quantity is used in an adjectival sense, a space is left between the numerical value and the unit symbol. (This rule recognizes that unit symbols are not like ordinary words or abbreviations but are mathematical entities, and that the value of a quantity should be expressed in a way that is as independent of language as possible — see sections 6.5 and 6.9.3.)

   Examples: a 1 m end gauge *but not:* a 1−m end gauge
   a 10 kV resistor *but not:* a 10−kV resistor

However, if there is any ambiguity, the words should be rearranged accordingly. For example, the statement "the samples were placed in 22 mL vials" should be replaced with the statement "the samples were placed in vials of volume 22 mL."

Note: When unit names are spelled out, the normal rules of English apply. Thus, for example, "a roll of 35-millimetre film" is acceptable (see section 6.5, note 3).

5.1.8 Unacceptability of unit symbols and unit names together

Unit symbols and unit names are not used together. (See also sections 7.5 and 7.8.)

Example: C/kg, $\mathrm{C \cdot kg^{-1}}$, or coulomb per kilogram

but not:
coulomb/kg;
coulomb per kg;
C/kilogram;
$\mathrm{coulomb \cdot kg^{-1}}$;
C per kg;
coulomb/kilogram

5.1.9 Unacceptability of abbreviations for units

Because acceptable units generally have internationally recognized symbols and names, it is not permissible to use abbreviations for their unit symbols or names, such as sec (for either s or second), sq. mm (for either mm^2 or square millimetre), cc (for either cm^3 or cubic centimetre), mins (for either min or minutes), hrs (for either h or hours), lit (for either L or litre), amps (for either A or amperes), AMU (for either u or unified atomic mass unit), or mps (for either m/s or metre per second). Although the values of quantities are normally expressed using symbols for numbers and symbols for units (see section 6.5), if for some reason the name of a unit is more appropriate than the unit symbol (see section 6.5, note 3), the name of the unit should be spelled out in full.

5.2 Rules and style conventions for SI prefixes

The following sections give rules and style conventions related to the SI prefixes.

5.2.1 Typeface and spacing

Prefix symbols are printed in roman (upright) type regardless of the type used in the surrounding text, and are attached to unit symbols without a space between the prefix symbol and the unit symbol. This last rule also applies to prefixes attached to unit names.

Examples: mL (millilitre) pm (picometre) GΩ (gigaohm) THz (terahertz)

5.2.2 Capitalization

The prefix symbols Y (yotta), Z (zetta), E (exa), P (peta), T (tera), G (giga), and M (mega) are printed in upper-case letters while all other prefix symbols are printed in lower-case letters (see table 5). Prefixes are normally printed in lower-case letters.

5.2.3 Inseparability of prefix and unit

The grouping formed by a prefix symbol attached to a unit symbol constitutes a new inseparable symbol (forming a multiple or submultiple of the unit concerned) which can be raised to a positive or negative power and which can be combined with other unit symbols to form compound unit symbols.

Examples: $2{,}3\ \mathrm{cm}^3 = 2{,}3\ (\mathrm{cm})^3 = 2{,}3\ (10^{-2}\ \mathrm{m})^3 = 2{,}3\times10^{-6}\ \mathrm{m}^3$

$1\ \mathrm{cm}^{-1} = 1\ (\mathrm{cm})^{-1} = 1\ (10^{-2}\ \mathrm{m})^{-1} = 10^2\ \mathrm{m}^{-1}$

$5000\ \mathrm{\mu s}^{-1} = 5000\ (\mathrm{\mu s})^{-1} = 5000\ (10^{-6}\ \mathrm{s})^{-1} = 5\times10^9\ \mathrm{s}^{-1}$

$1\ \mathrm{V/cm} = (1\ \mathrm{V})/(10^{-2}\ \mathrm{m}) = 10^2\ \mathrm{V/m}$

Prefixes are also inseparable from the unit names to which they are attached. Thus, for example, millimetre, micropascal, and meganewton are single words.

5.2.4 Unacceptability of compound prefixes

Compound prefix symbols, that is, prefix symbols formed by the juxtaposition of two or more prefix symbols, are not permitted. This rule also applies to compound prefixes.

Example: nm (nanometre) *but not:* mμm (millimicrometre)

5.2.5 Use of multiple prefixes

In a derived unit formed by division, the use of a prefix symbol (or a prefix) in both the numerator and the denominator may cause confusion. Thus, for example, 10 kV/mm is acceptable, but 10 MV/m is often considered preferable because it contains only one prefix symbol and it is in the numerator.

In a derived unit formed by multiplication, the use of more than one prefix symbol (or more than one prefix) may also cause confusion. Thus, for example, 10 MV·ms is acceptable, but 10 kV·s is often considered preferable.

Note: Such considerations usually do not apply if the derived unit involves the kilogram. For example, 0,13 mmol/g is not considered preferable to 0,13 mol/kg.

5.2.6 Unacceptability of stand-alone prefixes

Prefix symbols cannot stand alone and thus cannot be attached to the number 1, the symbol for the unit one. In a similar vein, prefixes cannot be attached to the name of the unit one, that is, to the word “one.“ (See section 6.9 for a discussion of the unit one.)

Example: the number density of Pb atoms is $5\times10^6/\mathrm{m}^3$ *but not:* the number density of Pb atoms is $5\ \mathrm{M/m}^3$

5.2.7 Prefixes and the kilogram

For historical reasons, the name “kilogram” for the SI base unit of mass contains the name “kilo,” the SI prefix for 10^3. Thus, because compound prefixes are unacceptable (see section 5.2.4), symbols for decimal multiples and submultiples of the unit of mass are formed by attaching SI prefix symbols to g, the unit symbol for gram, and the names of such multiples and submultiples are formed by attaching SI prefixes to the name “gram.”

Example:	10^{-6} kg =1 mg (1 milligram)	*but not:*	10^{-6} kg = 1 μkg (1 microkilogram)

5.2.8 Prefixes with the degree Celsius and units accepted for use with the SI

Prefix symbols may be used with the unit symbol °C and prefixes may be used with the unit name “degree Celsius.” For example, 12 m°C (12 millidegrees Celsius) is acceptable. However, to avoid confusion, prefix symbols (and prefixes) are not used with the time- related unit symbols (names) min (minute), h (hour), d (day); nor with the angle-related symbols (names) ° (degree), ′ (minute), and ″ (second) (see table 7).

Prefix symbols (and prefixes) may be used with the unit symbols (names) L (litre), t (metric ton), eV (electronvolt), and u (unified atomic mass unit) (see tables 7 and 8). However, although submultiples of the litre such as mL (millilitre) and dL (decilitre) are in common use, multiples of the litre such as kL (kilolitre) and ML (megalitre) are not. Similarly, although multiples of the metric ton such as kt (kilometric ton) are commonly used, submultiples such as mt (milli-metric ton), which is equal to the kilogram (kg), are not. Examples of the use of prefix symbols with eV and u are 80 MeV (80 megaelectronvolts) and 15 nu (15 nanounified atomic mass units).

6 Rules and Style Conventions for Expressing Values of Quantities

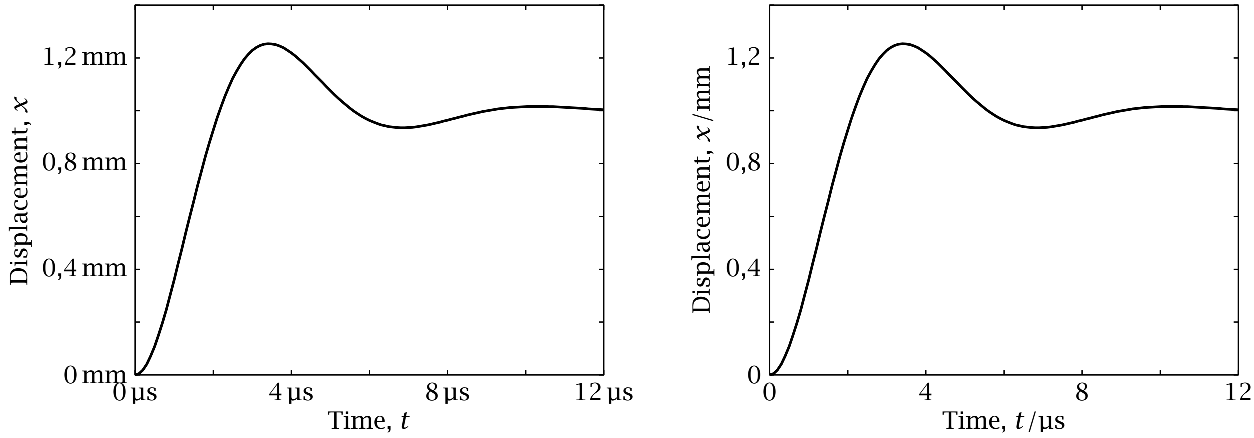
6.1 Value and numerical value of a quantity

The *value* of a quantity is its magnitude expressed as the product of a number and a unit, and the number multiplying the unit is the *numerical* value of the quantity expressed in that unit.

More formally, the value of quantity A can be written as $A = \{A\}[A]$, where $\{A\}$ is the numerical value of A when the value of A is expressed in the unit $[A]$. The numerical value can therefore be written as $\{A\} = A/[A]$, which is a convenient form for use in figures and tables. Thus, to eliminate the possibility of misunderstanding, an axis of a graph or the heading of a column of a table can be labelled "$t/{}^\circ\mathrm{C}$" instead of "$t\ ({}^\circ\mathrm{C})$" or "Temperature (°C)." Similarly, an axis or column heading can be labelled "$E/(\mathrm{V/m})$" instead of "$E\ (\mathrm{V/m})$" or "Electric field strength (V/m)."

Example:

1. In the SI, the value of the velocity of light in vacuum is $c = 299\,792\,458\ \mathrm{m/s}$ exactly. The number 299 792 458 is the numerical value of c when c is expressed in the unit m/s, and equals $c/(\mathrm{m/s})$.
2. The ordinate of a graph is labeled $T/(10^3\ \mathrm{K})$, where T is thermodynamic temperature and K is the unit symbol for kelvin, and has scale marks at 0, 1, 2, 3, 4, and 5. If the ordinate value of a point on a curve in the graph is estimated to be 3,2, the corresponding temperature is $T/(10^3\ \mathrm{K}) = 3{,}2$ or $T = 3200\ \mathrm{K}$. Notice the lack of ambiguity in this form of labeling compared with "Temperature (10^3 K)." See figures 1(a) and 1(b) for an example.
3. An expression such as $\ln(p/\mathrm{MPa})$, where p is the quantity symbol for pressure and MPa is the unit symbol for megapascal, is perfectly acceptable



(a) Units included with the scale of the graph. This form is usually difficult to obtain with most graphing software.

(b) The graph labels includes the units and the scales are dimensionless. Notice that there is no ambiguity with this form of labeling, because everything makes mathematical sense.

Figure 1: Graph labels

because p/MPa is the numerical value of p when p is expressed in the unit MPa and is simply a number.

Notes:

1. For the conventions concerning the grouping of digits, see section 4.2.
2. An alternative way of writing $c/(\text{m/s})$ is $\{c\}_{\text{m/s}}$, meaning the numerical value of c when c is expressed in the unit m/s.

6.2 Number of units per value of a quantity

The value of a quantity is expressed using no more than one unit.

Example: $l = 10{,}234$ m *but not:* $l = 10$ m 23 cm 4 mm

Note: Expressing the values of time intervals and of plane angles are exceptions to this rule. However, it is preferable to divide the degree decimally. Thus one should write 22,20° rather than 22°12′, except in fields such as cartography and astronomy.

6.3 Unacceptability of attaching information to units

When one gives the value of a quantity, it is incorrect to attach letters or other symbols to the unit in order to provide information about the quantity or its conditions of measurement. Instead, the letters or other symbols should be attached to the quantity.

Example: $V_{\text{max}} = 1000\ \text{V}$ *but not:* $V = 1000\ \text{V}_{\text{max}}$

Note: V is a quantity symbol for potential difference.

6.4 Unacceptability of mixing information with units

When one gives the value of a quantity, any information concerning the quantity or its conditions of measurement must be presented in such a way as not to be associated with the unit. This means that quantities must be defined so that they can be expressed solely in acceptable units (including the unit one – see section 6.9).

Example:

the Pb content is 5 ng/L	*but not:*	5 ng Pb/L or 5 ng of lead/L
the sensitivity for NO_3 molecules is $5\times10^{10}/\text{cm}^3$	*but not:*	the sensitivity is 5×10^{10} NO_3 molecules/cm^3
the neutron emission rate is $5\times10^{10}/\text{s}$	*but not:*	the emission rate is 5×10^{10} n/s
the number density of O_2 atoms is $3\times10^{18}/\text{cm}^3$	*but not:*	the density is 3×10^{18} O_2 atoms/cm^3
the resistance per square is 100 Ω	*but not:*	the resistance is 100 V/square

6.5 Symbols for numbers and units versus spelled-out names of numbers and units

This *Guide* takes the position that the key elements of a scientific or technical paper, particularly the results of measurements and the values of quantities that influence the measurements, should be presented in a way that is as independent of language as possible. This will allow the paper to be understood by as broad an audience as possible, including readers with limited knowledge of English. Thus, to promote the comprehension of quantitative information in general and its broad understandability in particular, values of quantities should be expressed in acceptable units using

- the Arabic symbols for numbers, that is, the Arabic numerals, not the spelled-out names of the Arabic numerals; and
- the symbols for the units, not the spelled-out names of the units.

Example:	the length of the laser is 5 m	*but not:*	the length of the laser is five metres
	the sample was annealed at a temperature of 955 K for 12 h	*but not:*	the sample was annealed at a temperature of 955 kelvins for 12 hours

Notes:

1. If the intended audience for a publication is unlikely to be familiar with a particular unit symbol, it should be defined when first used.
2. Because the use of the spelled-out name of an Arabic numeral with a unit symbol can cause confusion, such combinations must strictly be avoided. For example, one should never write “the length of the laser is five m.”
3. Occasionally, a value is used in a descriptive or literary manner and it is fitting to use the spelled-out name of the unit rather than its symbol. Thus it is considered acceptable for statements such as “the reading lamp was designed to take two 60-watt light bulbs,” or “the rocket journeyed uneventfully across 380 000 kilometres of space,” or “they bought a roll of 35-millimetre film for their camera.”
4. A general rule is that symbols for numbers are always to be used when one expresses (a) the value of a quantity in terms of a unit of measurement, (b) time (including dates), and (c) an amount of money.

6.6 Clarity in writing values of quantities

The value of a quantity is expressed as the product of a number and a unit (see section 6.1). Thus, to avoid possible confusion, the position is taken that values of quantities must be written so that it is completely clear to which unit symbols the numerical values of the quantities belong. Also to avoid possible confusion, this *Guide* strongly recommends that the word “to” be used to indicate a range of values for a quantity instead of a range dash (that is, a long hyphen) because the dash could be misinterpreted as a minus sign. (The first of these recommendations once again recognizes that unit symbols are not like ordinary words or abbreviations but are mathematical entities — see section 5.1.7.)

Examples:

51 mm × 51 mm × 25 mm *but not:* 51 × 51 × 25 mm
225 nm to 2400 nm or (225 to 2400) nm *but not:* 225 to 2400 nm
0 °C to 100 °C or (0 to 100) °C *but not:* 0 °C – 100 °C
0 V to 5 V or (0 to 5) V *but not:* 0 – 5 V
(8,2, 9,0, 9,5, 9,8, 10,0) GHz *but not:* 8,2, 9,0, 9,5, 9,8, 10,0 GHz
63,2 m ± 0,1 m or (63,2 ± 0,1) m *but not:* 63,2 ± 0,1 m or 63,2 m ± 0,1
129 s – 3 s = 126 s or (129 – 3) s = 126 s *but not:* 129 – 3 s = 126 s

Note: For the conventions concerning the use of the multiplication sign, see section 4.3.

6.7 Unacceptability of stand-alone unit symbols

Symbols for units are never used without numerical values or quantity symbols (they are not abbreviations).

Examples:

there are 10^6 mm in 1 km *but not:* there are many mm in a km
it is sold by the cubic metre *but not:* it is sold by the m^3
$t/{}^\circ\mathrm{C}$, $E/(\mathrm{V/m})$, p/MPa, and the like are perfectly acceptable (see section 6.1)

6.8 Choosing SI prefixes

The selection of the appropriate decimal multiple or submultiple of a unit for expressing the value of a quantity, and thus the choice of SI prefix, is governed by several factors. These include

- the need to indicate which digits of a numerical value are significant,
- the need to have numerical values that are easily understood, and
- the practice in a particular field of science or technology.

A digit is significant if it is required to express the numerical value of a quantity. In the expression $l = 1200$ m, it is not possible to tell whether the last two zeroes are significant or only indicate the magnitude of the numerical value of l. However, in the expression $l = 1{,}200$ km, which uses the SI prefix symbol for 10^3 (kilo, symbol k), the two zeroes are assumed to be significant because if they were not, the value of l would have been written $l = 1{,}2$ km.

It is often recommended that, for ease of understanding, prefix symbols should be chosen in such a way that numerical values are between 0,1 and 1000, and that only prefix symbols that represent the number 10 raised to a power that is a multiple of 3 should be used.

Example: $3{,}3\times10^7$ Hz may be written as 33×10^6 Hz = 33 MHz
0,009 52 g may be written as $9{,}52\times10^{-3}$ g = 9,52 mg
2703 W may be written as $2{,}703\times10^3$ W = 2,703 kW
$5{,}8\times10^{-8}$ m may be written as 58×10^{-9} m = 58 nm

However, the values of quantities do not always allow this recommendation to be followed, nor is it mandatory to try to do so.

In a table of values of the same kind of quantities or in a discussion of such values, it is usually recommended that only one prefix symbol should be used even if some of the numerical values are not between 0,1 and 1000.

Example: $10\ \text{mm} \times 3\ \text{mm} \times 0{,}02\ \text{mm}$ *is preferable to:* $1\ \text{cm} \times 3\ \text{mm} \times 20\ \mu\text{m}$

In certain kinds of engineering drawings it is customary to express all dimensions in millimetres. This is an example of selecting a prefix based on the practice in a particular field of science or technology.

6.9 Values of quantities expressed simply as numbers: the unit one, symbol 1

Certain quantities, such as refractive index, relative permeability, and mass fraction, are defined as the ratio of two mutually comparable quantities and thus are of dimension one (see section 6.13). The coherent SI unit for such a quantity is the ratio of two identical SI units and may be expressed by the number 1. However, the number 1 generally does not appear in the expression for the value of a quantity of dimension one. For example, the value of the refractive index of a given medium is expressed as $n = 1.51 \times 1 = 1.51$.

On the other hand, certain quantities of dimension one have units with special names and symbols which can be used or not depending on the circumstances. Plane angle and solid angle, for which the SI units are the radian (rad) and steradian (sr), respectively, are examples of such quantities (see section 1.2.1).

6.9.1 Decimal multiples and submultiples of the unit one

Because SI prefix symbols cannot be attached to the unit one (see section 5.2.6), powers of 10 are used to express decimal multiples and submultiples of the unit one.

Example: $\mu_\text{r} = 1{,}2\times10^{-6}$ *but not:* $\mu_\text{r} = 1{,}2\ \mu$

6.9.2 %, percentage by, fraction

In keeping with ISO 31 [5], the position is taken that it is acceptable to use the internationally recognized symbol % (percent) for the number 0,01 with the SI and thus to express the values of quantities of dimension one (see section 6.13) with its aid. When it is used, a space is left between the symbol % and the number by which it is multiplied [5]. Further, in keeping with section 6.5, the symbol % should be used, not the name "percent."

Example: $x_\text{B} = 0{,}0025 = 0{,}25\ \%$ *but not:* $x_\text{B} = 0{,}0025 = 0{,}25\%$ or
$x_\text{B} = 0.25$ percent

Because the symbol % represents simply a number, it is not meaningful to attach information to it (see section 6.3). One must therefore avoid using phrases such as "percentage by weight," "percentage by mass," "percentage by volume," or "percentage by amount of substance." Similarly, one must avoid writing, for example, "% (m/m)," "% (by weight)," "% (V/V)," "% (by volume)" or "% (mol/mol)."

The preferred forms are "the mass fraction is 0,10" or "the mass fraction is 10 %" or "$w_{\mathrm{B}} = 0{,}10$" or "$w_{\mathrm{B}} = 10\ \%$"; "the volume fraction is 0,35," or "the volume fraction is 35 %" or "$\varphi_{\mathrm{B}} = 0.35$" or "$\varphi_{\mathrm{B}} = 35\ \%$"; and "the amount-of-substance fraction is 0,15" or "the amount-of-substance fraction is 15 %" or "$x_{\mathrm{B}} = 0{,}15$" or "$x_{\mathrm{B}} = 15\ \%$." Mass fraction, volume fraction, and amount-of-substance fraction of B may also be expressed as in the following examples: $w_{\mathrm{B}} = 3$ g/kg; $\varphi_{\mathrm{B}} = 6{,}7$ mL/L; $x_{\mathrm{B}} = 185$ µmol/mol. Such forms are highly recommended. (See also section 6.9.3)

In the same vein, because the symbol % represents simply the number 0,01, it is incorrect to write, for example, "where the resistances R_1 and R_2 differ by 0,05 %" or "where the resistance R_1 exceeds the resistance R_2 by 0,05 %." Instead, one should write, for example, "where $R_1 = R_2(1 + 0{,}05\ \%)$" or define a quantity Δ via the relation $\Delta = (R_1 - R_2)/R_2$ and write "where $\Delta = 0{,}05\ \%$." Alternatively, in certain cases, the word "fractional" or "relative" can be used. For example, it would be acceptable to write "the fractional increase in the resistance of the 10 kV reference standard in 1994 was 0,002 %."

6.9.3 ppm, ppb, and ppt

In keeping with ISO 31 [5], the position is taken that the language-dependent terms part per million, part per billion and part per trillion, and their respective abbreviations "ppm," "ppb," and "ppt" (and similar terms and abbreviations), are not acceptable for use with the SI to express the values of quantities. Forms such as those given in the following examples should be used instead.

Example:

a stability of 0,5 (µA/A)/min	*but not:*	a stability of 0,5 ppm/min
a shift of 1,1 nm/m	*but not:*	a shift of 1,1 ppb
a frequency change of $0{,}35\times10^{-9}\,f$	*but not:*	a frequency change of 0,35 ppb
a sensitivity of 2 ng/kg	*but not:*	a sensitivity of 2 ppt

the relative expanded uncertainty of the resistance R is $U_{\mathrm{r}} = 3\ \mu\Omega/\Omega$

or

the expanded uncertainty of the resistance R is $U = 3\times10^{-6}\,R$

or

the relative expanded uncertainty of the resistance R is $U_{\mathrm{r}} = 3\times10^{-6}$

but not:

the relative expanded uncertainty of the resistance R is $U_{\mathrm{r}} = 3$ ppm

Because the names of numbers 10^9 and larger are not uniform worldwide, it is best that they be avoided entirely (in most countries, 1 billion = 1×10^{12} , not 1×10^{9} as in the United States); the preferred way of expressing large numbers is to use powers of 10. This ambiguity in the names of numbers is one of the reasons why the use of ppm, ppb, ppt, and the like is deprecated. Another, and a more important one, is that it is inappropriate to use abbreviations that are language dependent together with internationally recognized signs and symbols, such as MPa, ln, 10^{13} , and %, to express the values of quantities and in equations or other mathematical expressions (see also section 6.5).

Note: It is recognized that in certain cases the use of ppm, ppb, and the like may be required by a law or a regulation.

6.9.4 Roman numerals

It is unacceptable to use Roman numerals to express the values of quantities. In particular, one should not use C, M, and MM as substitutes for 10^2, 10^3 , and 10^6, respectively.

6.10 Quantity equations and numerical-value equations

A quantity equation expresses a relation among quantities. An example is $l = yt$, where l is the distance a particle in uniform motion with velocity y travels in the time t.

Because a quantity equation such as $l = yt$ is independent of the units used to express the values of the quantities that compose the equation, and because l, y, and t represent quantities and not numerical values of quantities, it is incorrect to associate the equation with a statement such as "where l is in metres, y is in metres per second, and t is in seconds."

On the other hand, a numerical value equation expresses a relation among numerical values of quantities and therefore does depend on the units used to express the values of the quantities. For example,

$$\{l\}_{\mathrm{m}} = 3{,}6^{-1}\{v\}_{\mathrm{km/h}}\,\{t\}_{\mathrm{s}}$$

expresses the relation among the numerical values of l, y, and t only when the values of l, y, and t are expressed in the units metre, kilometre per hour, and second, respectively. (Here $\{A\}_{\mathrm{X}}$ is the numerical value of quantity A when its value is expressed in the unit X — see section 6.1, note 2.)

An alternative way of writing the above numerical value equation, and one that is preferred because of its simplicity and generality, is

$$l/\mathrm{m} = 3{,}6^{-1}[v/(\mathrm{km/h})](t/\mathrm{s}).$$

Authors should consider using this preferred form instead of the more traditional form "$l = 3{,}6^{-1}vt$, where l is in metres, v is in kilometres per hour, and t is in seconds." In fact, this form is still ambiguous because no clear distinction is made between a quantity and its numerical value. The correct statement is, for example, "$l^* = 3{,}6^{-1}v^*t^*$, where l^* is the numerical value of the distance l travelled by a particle in uniform motion when l is expressed in metres, v^* is the numerical value of the velocity v of the particle when v is expressed in kilometres per hour, and t^* is the numerical value of the time of travel t of the particle when t is expressed in seconds." Clearly, as is done here, it is important to use different symbols for quantities and their numerical values to avoid confusion.

It is strongly recommended that because of their universality, quantity equations should be used in preference to numerical-value equations. Further, if a numerical value equation is used, it should be written in the preferred form given in the above paragraph and if at all feasible, the quantity equation from which it was obtained should be given.

Note: 1. Two other examples of numerical-value equations written in the preferred form are as follows, where E_g is the gap energy of a compound semiconductor and κ is the conductivity of an electrolytic solution:

$$E_g/\text{eV} = 1{,}425 - 1{,}337x + 0{,}270x^2,\ 0 \leq x \leq 0{,}15,$$

where x is an appropriately defined amount-of-substance fraction.

$$\frac{\kappa}{(\text{S/cm})} = 0{,}065\,135 + 1{,}7140\times10^{-3}(t/{^\circ}\text{C}) + 6{,}4141\times10^{-6}(t/{^\circ}\text{C})^2 - 4{,}5028\times10^{-8}(t/{^\circ}\text{C})^3, \quad 0\ {^\circ}\text{C} \leq t \leq 50\ {^\circ}\text{C},$$

where t is Celsius temperature.

2. Writing numerical-value equations for quantities expressed in inch-pound units in the preferred form will simplify their conversion to numerical-value equations for the quantities expressed in units of the SI.

6.11 Proper names of quotient quantities

Derived quantities formed from other quantities by division are written using the words “divided by” rather than the words “per unit” in order to avoid the appearance of associating a particular unit with the derived quantity.

Example: pressure is force divided by area *but not:* pressure is force per unit area

6.12 Distinction between an object and its attribute

To avoid confusion, when discussing quantities or reporting their values, one should distinguish between a phenomenon, body, or substance, and an attribute ascribed to it. For example, one should recognize the difference between a body and its mass, a surface and its area, a capacitor and its capacitance, and a coil and its inductance. This means that although it is acceptable to say “an object of mass 1 kg was attached to a string to form a pendulum,” it is not acceptable to say “a mass of 1 kg was attached to a string to form a pendulum.”

6.13 Dimension of a quantity

Any SI derived quantity Q can be expressed in terms of the SI base quantities length (l), mass (m), time (t), electric current (I), thermodynamic temperature (T), amount of substance (n), and luminous intensity (I_v) by an equation of the form

$$Q = l^\alpha\, m^\beta\, t^\gamma\, I^\delta\, T^\varepsilon\, n^\zeta\, I_v^\eta \sum_{k=1}^{K} a_k\ ,$$

where the exponents α, β, γ, ... are numbers and the factors a_k are also numbers. The dimension of Q is defined to be

$$\dim Q = \mathsf{L}^\alpha\, \mathsf{M}^\beta\, \mathsf{T}^\gamma\, \mathsf{I}^\delta\, \Theta^\varepsilon\, \mathsf{N}^\zeta\, \mathsf{J}^\eta\ ,$$

where L, M, T, I, Θ, N, and J are the *dimensions* of the SI base quantities length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity, respectively. The exponents α, β, γ, … are called "dimensional exponents." The SI derived unit of Q is $\mathrm{m}^{\alpha}\cdot\mathrm{kg}^{\beta}\cdot\mathrm{s}^{\gamma}\cdot\mathrm{A}^{\delta}\cdot\mathrm{K}^{\varepsilon}\cdot\mathrm{mol}^{\zeta}\cdot\mathrm{cd}^{\eta}$, which is obtained by replacing the dimensions of the SI base quantities in the dimension of Q with the symbols for the corresponding base units.

Example: Consider a nonrelativistic particle of mass m in uniform motion which travels a distance l in a time t. Its velocity is $v = l/t$ and its kinetic energy is $E_{\mathrm{k}} = mv^2/2 = l^2mt^{-2}/2$. The dimension of E_{k} is $\dim E_{\mathrm{k}} = \mathsf{L}^2\mathsf{M}\mathsf{T}^{-2}$ and the dimensional exponents are 2, 1, and -2. The SI derived unit of E_{k} is then $\mathrm{m}^2\cdot\mathrm{kg}\cdot\mathrm{s}^{-2}$, which is given the special name "joule" and special symbol J.

A derived quantity of dimension one, which is sometimes called a "dimensionless quantity," is one for which all of the dimensional exponents are zero: $\dim Q = 1$. It therefore follows that the derived unit for such a quantity is also the number one, symbol 1, which is sometimes called a "dimensionless derived unit."

Example: The mass fraction w_{B} of a substance B in a mixture is given by $w_{\mathrm{B}} = m_{\mathrm{B}}/m$, where m_{B} is the mass of B and m is the mass of the mixture. The dimension of w_{B} is $\dim w_{\mathrm{B}} = \mathsf{M}^1\mathsf{M}^{-1} = 1$; all of the dimensional exponents of w_{B} are zero, and its derived unit is $\mathrm{kg}^1\cdot\mathrm{kg}^{-1} = 1$ also.

7 Rules and Style Conventions for Spelling Unit Names

The following sections give rules and style conventions related to spelling the names of units.

7.1 Capitalization

When spelled out in full, unit names are treated like ordinary English nouns. Thus the names of all units start with a lower-case letter, except at the beginning of a sentence or in capitalized material such as a title.

In keeping with this rule, the correct spelling of the name of the unit °C is "degree Celsius" (the unit "degree" begins with a lower case "d" and the modifier "Celsius" begins with an uppercase "C" because it is the name of a person).

7.2 Plurals

Plural unit names are used when they are required by the rules of English grammar. They are normally formed regularly, for example, "henries" is the plural of henry. The following plurals are irregular: Singular — lux, hertz, siemens; Plural — lux, hertz, siemens. (See also section 7.7.)

7.3 Spelling unit names with prefixes

When the name of a unit containing a prefix is spelled out, no space or hyphen is used between the prefix and unit name (see section 5.2.3).

Examples:	milligram	*but not:*	milli-gram
	kilopascal	*but not:*	kilo-pascal

There are three cases where the final vowel of an SI prefix is commonly omitted: megohm (not megaohm), kilohm (not kiloohm), and hectare (not hectoare). In all other cases where the unit name begins with a vowel, both the final vowel of the prefix and the vowel of the unit name are retained and both are pronounced.

7.4 Spelling unit names obtained by multiplication

When the name of a derived unit formed from other units by multiplication is spelled out, a space, which is preferred this Guide, or a hyphen is used to separate the names of the individual units.

Example: pascal second or pascal-second

7.5 Spelling unit names obtained by division

When the name of a derived unit formed from other units by division is spelled out, the word "per" is used and not a solidus. (See also sections 5.1.8 and 7.8.)

Example: ampere per meter (A/m) *but not:* ampere/meter

7.6 Spelling unit names raised to powers

When the names of units raised to powers are spelled out, modifiers such as "squared" or "cubed" are used and are placed after the unit name.

Example: meter per second squared ($\mathrm{m/s^2}$)

The modifiers "square" or "cubic" may, however, be placed before the unit name in the case of area or volume.

Examples:	square centimeter ($\mathrm{cm^2}$)	ampere per square meter ($\mathrm{A/m^2}$)
	cubic millimeter ($\mathrm{mm^3}$)	kilogram per cubic meter ($\mathrm{kg/m^3}$)

7.7 Other spelling conventions

A derived unit is usually singular in English, for example, the value $3\ \mathrm{m^2{\cdot}K/W}$ is usually spelled out as "three square meter kelvin per watt," and the value $3\ \mathrm{C{\cdot}m^2/V}$ is usually spelled out as "three coulomb meter squared per volt." However, a "single" unit may be plural; for example, the value 5 kPa is spelled out as "five kilopascals," although "five kilopascal" is acceptable. If in such a single-unit case the number is less than one, the unit is always singular when spelled out; for example, 0,5 kPa is spelled out as "five-tenths kilopascal."

Note: These other spelling conventions are given for completeness; as indicated in section 6.5. The position is taken that symbols for numbers and units should be used to express the values of quantities, not the spelled-out names of numbers and units. Reference [4] also requires that a symbol for a number be used whenever the value of a quantity is expressed in terms of a unit of measurement.

7.8 Unacceptability of applying mathematical operations to unit names

Because it could possibly lead to confusion, mathematical operations are not applied to unit names but only to unit symbols. (See also sections 5.1.8 and 7.5.)

Example: joule per kilogram or J/kg or $\mathrm{J \cdot kg^{-1}}$ *but not:* joule/kilogram or joule·kilogram^{-1}

References

[1] SABS M33a:1992, *The International Metric System (SI). Guide to the use of the SI in South Africa.* SABS, Pretoria, South Africa.

[2] *The International System of Units (SI)*, 7th ed., 1998, Bureau International des Poids et Mesures, Paris.
http://www.bipm.fr/pdf/si-brochure.pdf

[3] *The International System of Units (SI)*, Supplement to the 7th ed., 2000, Bureau International des Poids et Mesures, Paris.
http://www.bipm.fr/pdf/si-supplement2000.pdf

[4] *Guide for the Use of the International System of Units (SI).* Edited by B.N. Taylor, NIST Special Publication 811, 1995 ed., U.S. Goverment Printing Office, Washington, DC.
http://physics.nist.gov/cuu/Units/rules.html

[5] ISO Standards Handbook: *Quantities and Units.* International Organization for Standardization, Geneva, Switzerland, 1993.

This Handbook is a compalation of ISO 1000 [6] as well as:

ISO 31–0:1992,	General principles.
ISO 31–1:1992,	Space and time.
ISO 31–2:1992,	Periodic and related phenomena.
ISO 31–3:1992,	Mechanics.
ISO 31–4:1992,	Heat.
ISO 31–5:1992,	Electricity and magnetism.
ISO 31–6:1992,	Light and related electromagnetic radiations.
ISO 31–7:1992,	Acoustics.
ISO 31–8:1992,	Physical chemistry and molecular physics.
ISO 31–9:1992,	Atomic and nuclear physics.
ISO 31–10:1992,	Nuclear reactions and ionizing radiations.
ISO 31–11:1992,	Mathematical signs and symbols for use in physical sciences and technology.
ISO 31–12:1992,	Characteristic numbers.
ISO 31–13:1992,	Solid state physics.

[6] ISO 1000:1992, *SI units and recommendations for the use of their multiples and of certain other units*, International Organization for Standardization, Geneva, Switzerland, 1992.

[7] IEC 60027–2, *Letter symbols to be used in electrical technology – Part 2: Telecommunications and electronics.* International Electrotecnical Commission, Geneva, Switzerland, 1999.