The International System of Units

In accordance with the *Weights and Measures (National Standards) Amendment Act 1984*, most units of measurement used in Australia are those of the International System of Units (*Système International d'Unités*), which is symbolised in all languages as 'SI'.

The SI is a practical system of units that constitutes the modern form of the metric system. SI units are divided into two classes:

- base units
- derived units.

Together, the base and derived units form what is called a 'coherent set of units'. 'Coherent' is used here in the specialist sense to describe a system in which the units are mutually related by rules of multiplication and division with no numerical factor other than one. A most important practical implication of a coherent system is that there is only one unit for each physical quantity that we measure.

System of quantities

The system of quantities used with the SI units is set out by the International Organization for Standardization (ISO) in ISO 31:1992, Parts 0 to 13. ISO has adopted a system of physical quantities based on the seven base quantities corresponding to the seven base units of the SI, namely length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity. Other quantities, called 'derived quantities', are defined in terms of these seven base quantities; the relationships between derived quantities are expressed by a system of equations. It is the system of quantities and equations that is properly used with the SI units. The effect of the system is that SI units are the same everywhere in the world.

SI base units

Table 1 shows the seven base units from which all other SI units are derived.

Table 1 SI base units

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

SI derived units

SI derived units are expressed in terms of base units by means of the mathematical symbols of multiplication and division.

Some of these SI derived units are named according to their relationship to the unit on which they are based (see Table 2). Others have special names (see Table 3).

Where units are formed by the multiplication of other units, this can be shown:

- with unit symbols – by using either a raised dot with a space either side or simply a space

  A • s or A s

- with unit names – by using a space

  ampere second

Table 3 and Table 4 employ the spaced, raised dot with unit symbols, and the space with unit names, reflecting the practice set out in *The International System of Units, 1998, 7th edition, and supplement 2000: addenda and corrigenda to the 7th edition*, published by the Bureau International des Poids et Mesures.

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

Base 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^3
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.

Table 3 SI derived units with special names and symbols

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

(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 4.

(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 – for example, millidegree Celsius, m°C.

These special names and symbols may themselves be used to express other derived units. Table 4 shows some examples.

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

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

Decimal multiples and submultiples

A series of prefixes is used to form the decimal multiples and submultiples of SI units. Each prefix has a standard value, regardless of the unit to which it is attached. Thus a kilometre is 10^3 metres, a megajoule is 10^6 joules, and a nanosecond is 10^{-9} seconds. These prefixes are listed in Table 5.

Table 5 Prefixes for SI units

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

(a) Sometimes spelt 'deka'.

Measurement in Australia

The *National Measurement Act 1960* governs the use of measurements in Australia. Within this Act are:

- the *National Measurement Regulations (1999)*, which prescribe the Australian legal units of measurement of any physical quantity and the SI prefixes that may be used
- the *National Measurement Guidelines (1999)*, which prescribe the way in which units of measurement and prefixes may be combined to produce an Australian legal unit of measurement.

Although SI units are always preferred, there are some non-SI units that are still accepted for use with the SI. Table 6 shows those non-SI units that have been adopted as legal units of measurement in Australia and that may be used generally. However, they are not all legally accepted in every nation, so care should be taken when using them.

Table 6 Non-SI Australian legal units of measurement

Quantity	*Name*	*Symbol*
sound power	decibel[(a)]	dB
sound pressure	decibel[(a)]	dB
sound intensity	decibel[(a)]	dB
area	hectare	ha
energy	electronvolt	eV
kinematic viscosity	stokes[(b)]	St
length	nautical mile	n mile[(c)]
mass	tonne	t
mass	metric carat	CM or ct[(c)]
plane angle	degree	°
plane angle	minute	‘
plane angle	second	“
time interval	day	d
time interval	hour	h
time interval	minute	min
velocity	knot	kn[(c)]
viscosity	poise[(b)]	P
volume	litre	L or l

(a) Not accepted for use with the International System

(b) These are centimetre-gram-seconds (CGS) units, the use of which is not encouraged within the International System.

(c) These symbols are legally accepted in Australia, but not internationally.

Certain units of measurement outside the SI system have special functions in particular industries or disciplines, including in mining, where gold continues to be measured in troy ounces (abbreviated to ‘oz tr’), and in aviation, where ‘foot’ (contracted to ‘ft’) remains the standard measurement for altitude.

The National Measurement Regulations prescribe the non-SI units that are additional Australian legal units of measurement and the purposes for which they may be used. Table 7 lists these units together with some examples of their prescribed purposes. However, Schedule 2 of the National Measurement Regulations should be considered to ascertain the specific purposes for which they may be legally used in Australia.

Using SI units

SI units can be expressed by either their name or their symbol. In non-technical works, the names of units should generally be used. In other publications, the type of content and the likely knowledge and expectations of readers will need to be considered. A consistent approach should be followed throughout a publication to avoid a haphazard mixture of unit names and unit symbols.

Consistency

Only one unit name or symbol should be included in a statement of measurement. For example:

1.234 m or 1234 mm

not

1 m 234 mm or 1 m 23 cm 4 mm

The unit chosen should be the one that makes the statement less cumbersome and easiest to grasp. For example:

47.32 m not 0.0047 32 km

500 kPa or 0.5 MPa but not 500 000 Pa

Only one unit for the physical quantities should be used when measurements are being compared, and in tables, lists and illustrations. Thus, in a table where quantities are expressed in metres, any millimetre value should be expressed as a (decimal) fraction of a metre.

Unit names and symbols should not be mixed in the same context. If a symbol is used for one unit, symbols should be used for all units. For example:

km/h not km/hour

Capitalisation

Except for the word Celsius in 'degree Celsius', units and their prefixes are not capitalised when shown in words (unless commencing a sentence). For example:

20 megatonnes not 20 Megatonnes

21 litres not 21 Litres

Most of the symbols are also presented in lower-case letters. The exceptions are:

- the symbol for litre (L), which is capitalised to make it clearer typographically, and is well established in this form in Australian style. (However, the lower-case 'l' is still listed as an option within the international and Australian standards)
- symbols for units named after people – for example, Pa for pascal and N for newton. Note that the unit name is spelt out in lower case but the first letter of the symbol is capitalised
- the symbols for the first seven prefixes shown in Table 5 – Y (yotta), Z (zetta), E (exa), P (peta), T (tera), G (giga) and M (mega).

Plurals

Unit symbols never take a plural s (since they are intentionally recognised symbols, not abbreviations of the unit names). Thus:

2 kg not 2 kgs

In contrast, the names of units do take a plural s when associated with numbers greater than one. Thus:

1 kilogram but 25 kilograms

1 metre but 1.5 metres

1 degree Celsius but 15 degrees Celsius

However, hertz, lux and siemens remain unchanged in the plural:

10 kilohertz 3 lux 1.5 siemens

Punctuation and spacing

When the SI symbols are used, they do not take full stops (unless ending a sentence). For example:

20 L not 20 L.

15 km not 15 km.

Both the names and symbols for SI units should be separated from the associated numerical value by a space. For example:

22 m not 22m

27 volts not 27volts

-15 °C not -15°C

However, the symbols for degree (°), minute (‘) and second (“) of plane angle do not take a space:

180° 125’ 15”

Using ‘per’

The word per should be used only with the spelt-out names of units of measurement, while the forward slash denoting per should be used only with symbols:

75 kilometres per hour or 75 km/h

not

75 kilometres/hour or 75 km per hour

Per should not be abbreviated to ‘p’. For example:

Mt/a not Mtpa

km/h not kmph or kph

Table 7 Some additional non-SI Australian legal units of measurement and the purpose for which they may be used

Quantity	*Name*	*Symbol*	*Examples of purpose*
length	inch	in	automotive tyres or rims, precision pipes, precision fittings, defence equipment, aviation equipment, equipment used in the computer or electronics industries
length	foot	ft	altitude used in aviation, submarine depth
mass	troy ounce	oz tr	the mass of precious metals
power	horsepower	hp	engine ratings in the aviation industry or defence equipment
pressure	millibar	mb or mbar	air pressure in the aviation industry
pressure	millimetre of mercury	mm Hg	blood pressure
velocity	foot per minute	ft/min	vehicular vertical speed
work and energy	kilocalorie	kcal	food energy vales

Other units of measurement

Bits and bytes

In information technology, two of the basic ways of measuring are bits and bytes – used for example, to measure computer memory storage and the transfer of data between computers:

- Bit: This refers to, and is a contraction of, the words ‘binary digit’.
- Byte: This word has no fixed definition, but IBM’s definition of it as a multiple of 8 bits has generally been accepted as a defacto standard.

Technically speaking, a bit is a unit and a byte is a multiple of a bit (8 times), in the same way that a kilometre is a multiple of a metre (1000 times). Worldwide, it is most common to use ‘B’ for byte and, either ‘b’ or ‘bit’ for binary digit.

The standard SI prefixes and their symbols are often used to form expressions such as kilobit (kb), megabyte (MB) and gigabyte (GB). Because information and computer technology operate on numbers with a base of two, not ten, these are not strictly accurate measurements – a kilobit should equal 1000 bits (10^3 bits), but is used to denote the amount 1024 bits (2^{10} bits). The relative inaccuracies increase for prefixes denoting higher powers, but these errors are often not important in texts of a non-technical nature. Where accuracy is important, the International Electrotechnical Commission (IEC), recognising that the SI prefix ‘kilo’ means 1000 not 1024, has approved a specific set of prefixes as an international standard (see Table 8).

Table 8 International Electrotechnical Commission prefixes

Prefix	*Symbol*	*Factor*	*Extended form*
exbi	Ei	$(2^{10})^6$	1 152 921 504 606 846 976
pebi	Pi	$(2^{10})^5$	1 125 899 906 824 624
tebi	Ti	$(2^{10})^4$	1 099 511 627 776
gibi	Gi	$(2^{10})^3$	1 073 741 824
mebi	Mi	$(2^{10})^2$	1 048 576
kibi	Ki	$(2^{10})^1$	1 024

Note: The IEC prefixes are all multiples. IEC has made no allowance for sub-multiples.

Imperial measurements

Imperial measurements (such as ‘inches’, ‘miles’, ‘pounds’, and ‘pints’) should be avoided, except in the following contexts:

- in quotations from historical documents (when SI equivalents can be provided in square brackets if relevant)
- when writing for readers in countries (particularly the United States of America) where imperial measures, or elements of them, still apply. In such instances, SI units can be followed by the relevant imperial units in parentheses if necessary.

Reference

Commonwealth of Australia 2002, Style Manual for authors, editors and printers, 6th edition (reprinted 2013), John Wiley & Sons Australia, Ltd. Part 2, Section 11, Pages 178 to 186.