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SI UNITS IN AAEC PUBLICATIONS

by

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FOREWORD

This note was prepared in response to repeated requests from authors for information on SI units. It is a quick ready-reference only. A complete description of the International System of Units (the SI) will be published by the Metrication Committee.

The text and tables are typed on an Adler electric typewriter and should be used by typists as a supplement to the Typing Guide.

CONTENTS

1. INTRODUCTION

The introduction to Australia of the metric system of measurement has been proceeding for some time, and should be substantially completed by 1980. Within the metric system, a refinement known as the International System of Units, or the SI, is increasingly being adopted exclusively by scientific and technical journals.

Commission Information Memorandum 3/1972 (18.8.72) promulgated the decision that metric units should be used exclusively in Commission reports. For scientific reporting, this effectively means the SI, and these notes provide certain basic information about the system and outline recommended standards for its use in Commission publications.

2. THE INTERNATIONAL SYSTEM OF UNITS (THE SI)

2.1 Historical Background

The SI is a logical development of the metre-kilogram-second system (MKS) which began to gain popularity early this century. In 1950 the International Electrotechnical Commission (IEC) adopted the ampere as the fourth base unit, thus linking the MKS system of units of mechanics with the electromagnetic units.

In 1954 the tenth General Conference of Weights and Measures (CGPM) adopted a system based on the four MKSA units, the degree kelvin as the base unit of temperature and the candela as the base unit of luminous intensity. In 1960 the eleventh CGPM formally adopted the title "Système International d'Unités", with the international abbreviation SI, and laid down rules for prefixes (see Section 4), and for derived and supplementary units (see Section 2.3). In 1971 the fourteenth CGPM formally adopted the mole as the base unit of amount of substance.

The SI units have been adopted by the International Organisation for Standardisation (ISO) and have been recommended by the national standardising bodies in many countries, including Australia.

2.2 Advantages of the SI

In addition to the obvious advantages offered by the prospect of uniformity, the SI is superior to any other system in current use in that it is a completely "coherent" system. In such a system the product or quotient of the units of any two quantities is the unit of the corresponding derived quantity; no unit-conversion factors are involved, and there is only one unit for each quantity. The SI can be extended to provide the units required for ALL branches of science, so that everyone can speak the same "language". An advantage of this situation is that analogies between different processes are no longer obscured by the use of different units.

2.3 Base, Supplementary and Derived Units

The seven SI base units are the metre, kilogram, second, ampere, kelvin, candela and mole. Two dimensionless supplementary units, the radian and steradian have also been adopted. These units and their symbols are shown in Table 1. Definitions of the units may be found in Australian Standard AS-1000 (SAA 1970) or in "SI, the International System of Units" (HMSO 1970).

From these units all others are derived, and for convenience special names and symbols have been given to some of the more important derived units. These names can be used in forming the names of further derived units, but all derived units can, if desired, be expressed in terms of base or supplementary units.

Table 2 lists the SI derived units which have special names and symbols, and Table 3 gives a selection of other derived units.

3. DISCUSSION OF THE SI

Some important features of the SI can be illustrated by a brief discussion of particular units. Each derived unit is built up from appropriate base or supplementary units. Thus, since acceleration is length divided twice by time, its unit is the metre per second squared ($m\ s^{-2}$). Force is proportional to mass times acceleration; its unit is therefore the kilogram metre per second squared ($kg\ m\ s^{-2}$), and it has the special name newton (N).

In some systems, the weight of unit mass is used as the unit of force - for example the kilogram-force or the pound-force. In such a system, if units of force and mass are to be related it is necessary to use a proportionality factor, g, having a value, in the appropriate units, equal to the arbitrary 'standard' gravitational acceleration. If, as is often the case, the force of gravity is not involved in the problem, its apparent introduction is a frequent source of error. The SI avoids this difficulty since the definition of the newton is independent of gravity.

Pressure is force divided by area; its unit is the newton per square metre ($N\ m^{-2}$), or it can be written in base units as $kg\ m^{-1}\ s^{-2}$. The unit has the more convenient special name pascal (Pa).

Energy (or work) is force times distance; its unit is the newton metre (N m, or $kg\ m^2\ s^{-2}$ in terms of base units) which has the special name joule (J). Heat is also a form of energy, but in many systems a special unit is used for it, so that heat must either be carefully distinguished from work or converted into the proper units by the 'mechanical equivalent of heat'. This spurious implied distinction between the thermal and mechanical forms of energy is removed in the SI by using the joule for both forms. Any implied distinction between thermal, mechanical, and electrical forms of power is similarly removed because the SI uses the joule per second ($J\ s^{-1}$) or watt (W) for all forms.

4. DECIMAL MULTIPLES AND SUB-MULTIPLES OF SI UNITS

4.1 Prefixes

In any system there will be units of inconvenient size for certain applications. This difficulty is overcome by the use of the SI multiplying prefixes; their names and symbols are shown in Table 4 with the corresponding multiplying factors.

Multiplying prefixes (or symbols) are written immediately adjacent to the unit names (or symbols) with which they are associated, and compound prefixes should not be used. For example, 10^{-9} metre is written 1 nanometre (1 nm) NOT 1 millimicrometre (1 mμm).

Once attached to a unit name a prefix becomes part of what is in effect the name of a new unit. Thus a power index affixed to a symbol containing a prefix indicates that the multiple or sub-multiple of the unit is raised to the power expressed by the index.

For example,

$$1\ km^2 = 1(km)^2 = 10^6 \text{ square metres}$$

NOT

$$1\ k(m)^2 = 10^3 \text{ square metres.}$$

Caution is needed when using the unit of mass, the kilogram whose name, for historical reasons, already contains a prefix. The name gram (or its symbol g) is used in association with prefixes (mg NOT μkg, μg NOT nkg) and as if it were the name of a unit (to avoid the absurdity of 'millikilogram').

To avoid errors in calculations it is strongly recommended that only unprefixed SI units be used in combination to form derived units, or that any prefixes be replaced by powers of ten before embarking on calculations. Where possible, any numerical prefix should appear in the numerator of an expression. If, for example, a unit such as the MJ dm^{-3} is encountered, write MJ $dm^{-3} = 10^6\ J(10^{-1}m)^{-3} = 10^9 J\ m^{-3}$. It would be preferable to call this unit a gigajoule per cubic metre, or GJ m^{-3}.

4.2 Preferred Prefixes

Australian Standard AS-1000 "especially recommends" that prefixes representing 10 raised to a power which is a multiple of 3 be preferred; the hecto (10^2), deca (10), deci (10^{-1}) and centi (10^{-2}) are listed separately as being for "special use". Some journals, and the Royal Society Conference of Editors, also recommend this practice. It is NOT a requirement of the SI, and such prefixes may be used where convenient.

5. UNITS OUTSIDE THE SI

There are a number of units which, while not part of the SI, are in widespread use. These units can conveniently be divided into three classes.

5.1 Units in Use with the SI

These are accepted for use with the SI because of their importance or common use in certain areas. They are shown in Table 5.

There are also four units, useful in specialised fields, whose values in SI units must be obtained by experiment and are therefore not known exactly. They are:

Name	Symbol	Approximate SI value of 1 unit
electronvolt	eV	1.60219×10^{-19} J
unified atomic mass unit	u	1.66053×10^{-27} kg
astronomical unit	AU	$149{,}600 \times 10^{6}$ m
parsec	pc	$30{,}857 \times 10^{12}$ m

5.2 Units Accepted Temporarily

Table 6 lists units which the CGPM considers should be retained for a "limited time". No definition of "limited" has been offered, and those units marked with an asterisk are to be avoided in AAEC publications.

5.3 Other Units

Units outside the SI which do not come under the headings 5.1 and 5.2 above are to be avoided. Table 7 is not complete, it contains only units which may in the past have been of interest to AAEC authors.

6. STANDARD AND RECOMMENDED NOTATION FOR THE SI

6.1 Unit Names and Symbols

The spellings "kilogram" and "metre" have been used throughout this note, and should be adopted in the interests of uniformity.

The names of units do not take a leading capital. Some journals have in the past used a leading capital for "kelvin". This is incorrect. The symbol ^{o}K is also incorrect. The symbol K should be used to express both temperatures and temperature intervals. Unit symbols do not change in the plural.

6.2 Compound Symbols

The symbol for the product of two units, e.g. the newton and the metre, can be written in five ways:

(i) Nm (no space)
(ii) N m (half space separation)
(iii) N·m (dot above line)
(iv) N.m (dot on the line)
(v) N m (full space separation).

Method (i) can lead to confusion between the symbol m as unit (metre) and prefix (milli). The ISO recommends the use of a multiplying dot, but says that it may be dispensed with when there is no risk of confusion with another unit symbol. For example N·m or Nm but not mN. Such mixture of conventions is not desirable.

Methods (ii) and (iii), although commonly used by journals, are not suitable for typing.

Method (v) will be adopted for AAEC/E series reports. Authors who choose to use method (iv) in internal reports must ensure that it is used consistently throughout the work.

A derived unit formed by division may be indicated by a solidus (oblique stroke, /) or by the use of negative indices.*

For example N/m^2 or $N\ m^{-2}$.

One solidus only is permitted, unless brackets are used to avoid ambiguity. However, negative indices avoid both ambiguity and the cumbrous use of brackets, and will be used in all AAEC publications.

For example, joule per kilogram per kelvin = $J\ kg^{-1}\ K^{-1}$. Other examples will be found in Table 3.

7. REFERENCES

SAA (1970). The International System (SI) Units and their Application. Standards Association of Australia. (AS-1000)

HMSO (1970). SI, The International System of Units. 1 National Physical Laboratory, Ministry of Technology, London.

8. ACKNOWLEDGEMENTS

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* A horizontal line, e.g. $\frac{N}{m^2}$, while permitted by ISO recommendations is unsuitable both for typing and type-setting.

TABLE 1 - SI BASE AND SUPPLEMENTARY UNITS

Quantity	Unit Name	Unit Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol
Plane angle	radian	rad
Solid angle	steradian	sr

TABLE 2 - SPECIAL NAMES AND SYMBOLS FOR SI DERIVED UNITS

Quantity	Unit Name	Unit Symbol	Expression in SI Base or Supplementary Units	Expression in other Units
Force	newton	N	kg m s^{-2}	
Pressure, stress	pascal	Pa	kg m^{-1} s^{-2}	N m^{-2}
Energy, work, quantity of heat	joule	J	kg m^2 s^{-2}	N m, W s
Power	watt	W	kg m^2 s^{-3}	J s^{-1}
Frequency	hertz	Hz	s^{-1}	
Electric charge	coulomb	C	A s	
Electric potential	volt	V	kg m^2 s^{-3} A^{-1}	W A^{-1}
Electric resistance	ohm	Ω	kg m^2 s^{-3} A^{-2}	V A^{-1}
Electric conductance	siemens	S	kg^{-1} m^{-2} s^3 A^2	A V^{-1}, Ω^{-1}
Electric capacitance	farad	F	kg^{-1} m^{-2} s^4 A^2	C V^{-1}
Magnetic flux	weber	Wb	kg m^2 s^{-2} A^{-1}	V s
Inductance	henry	H	kg m^2 s^{-2} A^{-2}	Wb A^{-1}
Magnetic flux density	tesla	T	kg s^{-2} A^{-1}	Wb m^{-2}
Luminous flux	lumen	lm	cd sr	
Illuminance	lux	lx	cd sr m^{-2}	lm m^{-2}

TABLE 3 - A SELECTION OF SI DERIVED UNITS

Quantity	Unit Name	Unit Symbol	Expression in SI Base or Supplementary Units
Area	square metre	m^2	m^2
Volume	cubic metre	m^3	m^3
Density	kilogram per cubic metre	$kg\ m^{-3}$	$kg\ m^{-3}$
Velocity	metre per second	$m\ s^{-1}$	$m\ s^{-1}$
Angular velocity	radian per second	$rad\ s^{-1}$	$rad\ s^{-1}$
Acceleration	metre per second squared	$m\ s^{-2}$	$m\ s^{-2}$
Kinematic viscosity	square metre per second	$m^2\ s^{-1}$	$m^2\ s^{-1}$
Dynamic viscosity	pascal second	Pa s	$kg\ m^{-1}\ s^{-1}$
Electric field strength	volt per metre	$V\ m^{-1}$	$kg\ m\ s^{-3}\ A^{-1}$
Magnetic field strength	ampere per metre	$A\ m^{-1}$	$A\ m^{-1}$
Specific heat	joule per kilogram kelvin	$J\ kg^{-1}\ K^{-1}$	$m^2\ s^{-2}\ K^{-1}$
Enthalpy	joule per kilogram	$J\ kg^{-1}$	$m^2\ s^{-2}$
Molar entropy, molar heat capacity	joule per mole kelvin	$J\ mol^{-1}\ K^{-1}$	$kg\ m^2\ s^{-2}\ mol^{-1}\ K^{-1}$
Coefficient of heat transfer	watt per square metre kelvin	$W\ m^{-2}\ K^{-1}$	$kg\ s^{-1}\ K^{-1}$

TABLE 4 - SI MULTIPLYING PREFIXES

tera	T	10^{12}	deci	d	10^{-1}
giga	G	10^{9}	centi	c	10^{-2}
mega	M	10^{6}	milli	m	10^{-3}
kilo	k	10^{3}	micro	μ	10^{-6}
hecto	h	10^{2}	nano	n	10^{-9}
deca	da	10^{1}	pico	p	10^{-12}
			femto	f	10^{-15}
			atto	a	10^{-18}

TABLE 5 - UNITS ACCEPTED FOR USE WITH THE SI

Name	Symbol	SI Value of One Unit
minute	min	60 s
hour	h	3,600 s
day	d	86,400 s
degree	o	(π/180) rad
minute	'	(π/10,800) rad
second	"	(π/648,000) rad
litre	ℓ	1 dm^3 = 10^{-3} m^3
tonne	t	1 Mg = 10^3 kg

Note Convenient SI equivalents exist for the litre and the tonne, and are preferred in AAEC reports.

TABLE 6 - UNITS ACCEPTED FOR LIMITED USE WITH THE SI

Name	Symbol	SI Value of One Unit
nautical mile		1,852 m
knot		$\left(\frac{1,852}{3,600}\right) m\ s^{-1}$
angstrom*	Å	$0.1\ nm = 10^{-10}\ m$
are*	a	$1\ dam^2 = 10^2 m^2$
hectare*	ha	$1\ hm^2 = 10^4 m^2$
barn	b	$100\ fm^2 = 10^{-28} m^2$
bar*	bar	$0.1\ MPa = 10^5\ Pa$
atmosphere*	atm	101,325 Pa
gal (a)	Gal	$1\ cm\ s^{-2} = 10^{-2}\ m\ s^{-2}$
curie	Ci	$3.7 \times 10^{10}\ s^{-1}$
röntgen	R	$2.58 \times 10^{-4}\ C\ kg^{-1}$
rad (b)	rad	$10^{-2}\ J\ kg^{-1}$

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

(b) The widespread medical use of the rad makes its retention necessary. Where there is risk of confusion with the symbol for radian, rd may be used as a symbol for rad.

* To be avoided in AAEC publications.

TABLE 7 - UNITS OUTSIDE THE SI WHICH ARE TO BE AVOIDED

Name	Symbol	SI Value of One Unit
erg	erg	10^{-7} J
dyne	dyn	10^{-5} N
fermi	fm	10^{-15} m
torr	torr	$\frac{101,325}{760}$ Pa
kilogram-force	kgf	9.80665 N
calorie	cal	4.1868 J *
micron	μ	10^{-6} m (1 μm)

* This is the value of the so-called IT (International Table) calorie.