GUIDELIES ON INTERNATIONAL SYSTEM OF UNITS

The term SI Units is an abbreviation of the French *Le Système International d'Unités*. It is the modern metric system of measurement. Established in 1960 by the 11^{th} General Conference on Weights and Measures (CGPM, *Conférence Générale des Poids et Mesures*), SI is now universally accepted as a standard system of measurement. The body, CGPM, is the recognized international authority to disseminate SI and modifies it to reflect the latest advances in science and technology. National Institute of Standards and Technology, USA has brought out books on these standards.

Use SI units in your thesis unless you have compelling reasons to use non-SI units.

The SI units consist of

(a) seven *base units*,
(b) a set of *prefixes*, and
(c) several *derived units*

The SI units follow a standard *writing style*.

The SI Base Units

The *SI base units* represent seven mutually independent *base quantities.* These quantities, their names, and the symbols that represent them are given in Table 1.

The Prefixes

A prefix may be added to any unit to produce an integer multiple of ten of the base unit. For example, a kilogram denotes a multiple of one thousand of a gram and a milligram denotes a multiple of a thousandth of a gram. Table 2 gives the prefixes that are accepted to be used in the SI units. Prefixes are never combined. For example, millimillimeter is not written; micrometer is written instead.

Table 1: The SI Base Units

Quantity	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	Cd

Table 2: The SI Prefixes

Name	yotta-	zetta-	exa-	peta-	tera-	giga-	mega-	kilo-	hecto-	deca-
Symbol	Y	Z	E	P	T	G	M	K	h	da
Factor	10^{24}	10^{21}	10^{18}	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	10^{2}	10^{1}
Name	deci-	centi-	milli-	micro-	nano-	pico-	femto-	Atto-	zepta-	yacto-
Symbol	d	C	m	µ	n	p	f	A	z	y
Factor	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}

The SI Derived Units

A system of equations involving the seven base quantities defines the *derived quantities*. The *SI derived units* follow these equations to represent the derived quantities. Table 3 gives examples of a number of SI derived units.

Table 3: Examples of SI Derived Units

Derived quantity	**Name**	**Symbol**
Area	square meter	m^2
Volume	cubic meter	m^3
wave number	reciprocal meter	m^{-1}
mass density	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
mass fraction	kilogram per kilogram, which may be represented by the number 1	kg/kg = 1*
speed, velocity	meter per second	m/s
Acceleration	meter per second squared	m/s^2
current density	ampere per square meter	A/m^2
Magnetic field strength	ampere per meter	A/m
amt-of-substance concentration	mole per cubic meter	mol/m^3
Luminance	candela per square meter	cd/m^2

* The symbol 1 for quantities of dimension 1 is generally omitted.

The SI Derived Units with Special Names and Symbols

Twenty-two derived units are given special names and symbols because they are in popular use for a long time. These units (names and symbols), together with the quantities they represent, and the expressions in terms of other SI units and base units, are given in Table 4.

Table 4: SI Derived Units with Special Names and Symbols

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
plane angle	radian	rad	-	$m \cdot m^{-1} = 1$
Solid angle	steradian	sr	-	$M^2 \cdot m^{-2} = 1$
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	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$

conductance				
Magnetic flux	weber	Wb	V·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	°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 (of a radionuclide)	becquerel	Bq	-	s^{-1}
Absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
Dose equivalent	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
Catalytic activity	katal	kat	-	$s^{-1} \cdot mol$

The SI Writing Style

The writing style for the SI units has been standardized. It is detailed below.

- Names of units are always written in lower case; their symbols are also written in lower case unless they are derived from names of specific persons.

Example:

Quantity	Name	Symbol	Explanation
mass	kilogram	kg	-
thermodynamic temperature	kelvin	K	Named after Lord Kelvin
pressure	pascal	Pa	Named after Blaise Pascal

Exception to the rule:

The Celsius temperature has the accepted name “degree Celsius” although it is named after the scientist Celsius, not “degree celsius”.

- A space separates the number and its symbol.

Examples: 25 kg, 3.2×10^{-2} m^3, 100 °C, and 300 K

Exception:

No space separates the symbols for plane angular degrees (°), minutes (′), and seconds (″) from the numbers they follow.

Examples: 10°, 5′, and 10″.

Note: The symbols °, ′, and ″ are to be selected from the list of symbols.

- A symbol is not followed by a period unless it appears at the end of a sentence.

  Example:

25 kg.	-	Incorrect
25 kg	-	Correct

- Symbols are not pluralized.

  Example:

25 kgs	-	Incorrect
25 kg	-	Correct

- Names of units are pluralized, whenever needed.

  Examples:

  25 kilograms and five millimeters

  Exceptions:

  The units lux, hertz, and siemens do not change their form in plural.

- A symbol is not italicized; it is written in upright Roman letters (such as “m” for meter and “s” for second) to distinguish them from italicized Roman letters used for mathematical variables (such as *m* for mass and *s* per specific gravity).

Example:

25 *kg* - Incorrect

25 kg - Correct

- Symbols for derived units formed by the product of multiple units are followed by either a space or a *center dot* (also called *raised dot*) separating individual unit symbols.

  Note: The center dot has to be selected from the list of symbols.

  Examples: N m <u>or</u> N·m, kg s <u>or</u> kg·s

- Symbols for derived units formed by division of two units are separated by a solidus (/) or indicated by a negative exponent or are represented by a fraction.

  Examples: m/s^2, $m\ s^{-2}$, $m \cdot s^{-2}$, <u>or</u> $\frac{m}{s^2}$

- While using both multiplication and division, use the above rules and ensure that there is no ambiguity in its interpretation.

  Examples: $kg \cdot s^{-2} \cdot A^{-1}$ <u>not</u> $kg/s^2 \cdot A$

  $kg \cdot m^{-1} \cdot s^{-2}$ <u>or</u> $kg/(m \cdot s^2)$ <u>not</u> $kg/m \cdot s^2$

- SI derived units may be used in conjunction with other derived units to denote other SI derived units (Table 5).

Table 5: Other SI Derived Units

Derived quantity	Name	Symbol
dynamic viscosity	pascal second	Pa·s
moment of force	newton meter	N·m
surface tension	newton per meter	N/m
angular velocity	radian per second	rad/s
angular acceleration	radian per second squared	rad/s^2
Heat flux density, irradiance	watt per square meter	W/m^2
Heat capacity, entropy	joule per Kelvin	J/K
specific heat capacity, specific entropy	joule per kilogram Kelvin	J/(kg·K)
specific energy	joule per kilogram	J/kg
thermal conductivity	watt per meter Kelvin	W/(m·K)
energy density	joule per cubic meter	J/m^3
electric field strength	volt per meter	V/m
electric charge density	coulomb per cubic meter	C/m^3
electric flux density	coulomb per square meter	C/m^2
Permittivity	farad per meter	F/m
Permeability	henry per meter	H/m
molar energy	joule per mole	J/mol
molar entropy, molar heat capacity	joule per mole Kelvin	J/(mol·K)
exposure (x and γ rays)	coulomb per kilogram	C/kg
absorbed dose rate	gray per second	Gy/s
radiant intensity	watt per steradian	W/sr
Radiance	watt per square meter steradian	$W/(m^2 \cdot sr)$
catalytic (activity) concentration	katal per cubic meter	kat/m^3

A few non-SI units are accepted for use with the SI units. They are given in Table 6.

Table 6: Non-SI Units Accepted for Use with the SI Units

Name	**Symbol**	**Value in SI units**
minute (time)	min	1 min = 60 s
Hour	h	1 h = 60 min = 3 600 s
Day	d	1 d = 24 h = 86 400 s
degree (angle)	°	1° = (π/180) rad
minute (angle)	′	1′ = (1/60)° = (π /10 800) rad
second (angle)	″	1″ = (1/60)′ = (π /648 000) rad
Liter	L	1 L = 1 dm^3 = 10^{-3} m^3
metric ton	t	1 t = 10^3 kg
neper	Np	1 Np = 1
Bel	B	1 B = (1/2) ln 10 Np
electronvolt	eV	1 eV = 1.602 18 x 10^{-19} J, approximately
unified atomic mass unit	u	1 u = 1.660 54 x 10^{-27} kg, approximately
astronomical unit	ua	1 ua = 1.495 98 x 10^{11} m, approximately

A few other non-SI units are also used along with the SI units (Table 7). But acceptance of this practice is under review.

Table 7: Non-SI Units Accepted For Use with SI Units (Subject to Further Review)

Name	Symbol	Value in SI units
Nautical mile	No symbol	1 nautical mile = 1 852 m
Knot	No symbol	1 nautical mile per hour = (1 852/3 600) m/s
are	a	1 a = 1 $dam^2 = 10^2$ m^2
Hectare	ha	1 ha = 1 $hm^2 = 10^4$ m^2
Bar	bar	1 bar = 0.1 MPa = 100 kPa = 1 000 hPa = 10^5 Pa
Angstrom	Å	1 Å = 0.1 nm = 10^{-10} m
Barn	b	1 b = 100 $fm^2 = 10^{-28}$ m^2
Curie	Ci	1 Ci = 3.7 x 10^{10} Bq
Roentgen	R	1 R = 2.58 x 10^{-4} C/kg
Radian	rad	1 rad = 1 cGy = 10^{-2} Gy
Rem	rem	1 rem = 1 cSv = 10^{-2} Sv

A few notable points are made below:

- Electrical energy is often measured in kilowatt-hours (kWh) instead of megajoules.
- As we know, "calorie" is used as a heat unit indicating the amount of heat required to raise the temperature of one gram of water by one degree Celsius.

  And "Calorie" is used as a heat unit indicating the amount of heat required to raise the temperature of one kilogram of water by one degree Celsius. Thus:

  A Calorie is a kilocalorie (or large calorie).

- Blood pressure is measured in mmHg instead of Pa.
- Atomic scale units used in physics and chemistry are ångström, electron volt, atomic mass unit, and barn.

- Astronomical distances are measured in astronomical units, parsecs, and light-years.
- Travel distance and speed of ships and aircraft are measured in nautical mile and knot (nautical mile per hour).
- The year is not specifically included as an SI unit.
- Litre has a symbol L and not the lowercase letter l to distinguish it from the numeral 1. In some countries, the italicized letter *l* is also used.
- A metric ton is called "tonne" in a few countries.
- Commas are used as thousand separators in many countries, whereas periods are used for this purpose in a few European countries. To avoid this confusion, SI units prescribe spaces as thousand separators.

  Examples:

  2 450 000, 45 000, 0.524 45

- It is preferred to use numbers between 0.1 and 1 000 in expressing the quantity of any SI unit. Thus the quantity 15 000 m is expressed as 15 km, and 0.002 cubic centimeter is preferably written as 2 mm^3.

- Note the following:

  - The symbol kg is a base symbol, but it has a prefix as part of its name and symbol.
  - Since multiple prefixes are not permitted, use of g is also permitted as a base symbol when prefixes are to be added.

    Thus: 10^{-6} kg = 1 mg, but not 1 μkg

- One kilobit or 1 kbit = 1 000 bit, but not equal to $2^{10} = 1\ 024$

To get over this problem, International Electrotechnical Commission (IEC) has adopted "Prefixes for Binary Multiples" for use in IT (Table 8).

Table 8: Prefixes for Biary Multiples

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

Thus the following equivalences hold:

one kibibit 1 Kibit = 2^{10} bit = 1 024 bit
one kilobit 1 kbit = 10^3 bit = 1 000 bit
one mebibyte 1 MiB = 2^{20} B = 1 048 576 B
one megabyte 1 MB = 10^6 B = 1 000 000 B
one gibibyte 1 GiB = 2^{30} B = 1 073 741 824 B
one gigabyte 1 GB = 10^9 B = 1 000 000 000 B

Note that the first prefix of the above symbols is borrowed from the SI convention, and the letter i is added to mean binary. To keep parity with the binary multiple prefixes, kilo is taken as K and not k (as done in SI). *Note further that these conventions are not yet accepted internationally.*