Systéme Internationale d´Unites
International System of Units

Prepared by Professor J R Lucas, Department of Electrical Engineering, University of Moratuwa

The International System of Units (SI Units) is a coherent system which has been accepted for use in almost all countries for scientific and technical work. A system is coherent if the product or quotient of any two unit quantities in the system is the unit of the resultant quantity. For example, in a coherent system, unit area results when unit length is multiplied by unit length; unit velocity when unit length is divided by unit time; and unit force when unit mass is multiplied by unit acceleration.

Base Units and Supplementary Units

SI Units consist of *seven base units* for seven *base quantities* which are defined as mutually independent *and two supplementary units.* All other units are derived from these units.

Base unit

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

Supplementary unit

Quantity	Name	Symbol
plane angle	radian	rad
solid angle	steradian	sr

Definitions

meter The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second [1983].

kilogram The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram [1901].

second 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 [1967].

ampere 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 meter apart in vacuum, would produce between these conductors a force equal to 2 x 10-7 newton per meter of length [1948].

kelvin The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water [1967].

mole The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12; [1971]

candela The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 1012 hertz and that has a radiant intensity in that direction of 1/683 watt per steradian [1979].

radian (rad) The radian is the plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius.

steradian (sr) The steradian is the solid angle that, having its vertex in the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

degrees celsius (^oC) It is an international thermometric scale on which the interval between the triple point of water and the boiling point of water is divided into 99.99 degrees with 0.01° representing the triple point and 100° the boiling point

Celsius degrees are the same size as kelvin but the zero point is shifted to the triple point of water, minus 0.01 K. (0 °C = 273.15 K).
Note: The thermodynamic temperature of the triple point of water is 273.16 K

SI Derived Units

The following SI units are have their own names but are not independently defined. They can be reduced in terms of the SI base units, and are thus known as derived units.

	SI derived unit			
Derived quantity	**Name**	**Symbol**	**In terms of other SI units**	**In terms of SI base units**
absorbed dose	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
decay activity	becquerel	Bq	-	s^{-1}
dose equivalent	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
electric charge	coulomb	C	-	$s \cdot A$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
electric potential difference	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
energy	joule	J	N· m	$m^2 \cdot kg \cdot s^{-2}$
frequency	hertz	Hz	-	s^{-1}
force	newton	N	-	$m \cdot kg \cdot s^{-2}$
illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
luminous flux	lumen	lm	cd· sr	cd
magnetic flux	weber	Wb	V· s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
power	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
pressure	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$

Some definitions of the SI derived units

farad (F) SI unit of electric capacitance. One farad is defined as the ability to store one coulomb of charge per volt of potential difference between the two conductors.

coulomb (C) SI unit of electric charge. One coulomb is equal to the amount of charge accumulated in one second by a current of one ampere.

siemens (S) SI unit of electric conductance. One siemens is equal to the conductance between two points of a conductor having a resistance of 1 Ω. siemens is the reciprocal of the ohm.

volt (V) SI unit of electric potential. One volt is equal to the potential difference between two points of a conducting wire carrying a constant current of 1 A, when the power dissipated between these points is equal to 1 W.

ohm (Ω) SI unit of electric resistance. One ohm is equal to the electric resistance between two points of a conductor when a constant potential difference of 1 V, applied to these points, produces in the conductor a current of 1 A, the conductor not being the seat of any electromotive force.

joule (J) SI unit of work or energy. One joule is defined to be the work done by a force of one newton acting to move an object through a distance of one meter in the direction in which the force is applied.

hertz (Hz) SI unit of frequency. One hertz is equal to one cycle per second.

newton (N) SI unit of force. One newton is equal to the force required to accelerate a body with the mass one kilogram by one metre per second per second

lux (lx) SI unit for measuring the illumination of a surface. One lux is defined as an illumination of one lumen per square meter.

henry (H) SI unit of electric inductance. One henry is equal to the inductance of a closed circuit in which an electromotive force of 1 volt is produced when the electric current in the circuit varies uniformly at the rate of 1 ampere per second

lumen (lm) SI unit for measuring the flux of light. One lumen is equal to the luminous flux emitted in unit solid angle (steradian) by uniform point source having a luminous intensity of 1 candela.

weber (Wb) SI unit of magnetic flux. One weber is equal to the magnetic flux which, linking a circuit of one turn, would produce in it an electromotive force of 1 V if it were reduced to zero at a uniform rate of 1 s.

tesla (T) SI unit of magnetic flux density. One tesla is defined as the field intensity generating one newton of force per ampere of current per meter of conductor.

watt (W) SI unit of power. One watt is equal to a power rate of one joule of work per second of time.

var IEC Unit of the reactive electric power. The reactive power is the product of the voltage and the reactive part of the current. The name is an acronym for volt-ampere-reactive.

pascal (Pa) SI unit of pressure. One pascal is equal to the force of one newton exerted on one square meter.

Prefixes - Decimal Multiples and Sub-multiples

Symbol	Prefix	Power of Ten	Ordinary Notation	Common Name
Y	yotta	10^{24}	1 000 000 000 000 000 000 000 000	
Z	zetta	10^{21}	1 000 000 000 000 000 000 000	
E	exa	10^{18}	1 000 000 000 000 000 000	
P	peta	10^{15}	1 000 000 000 000 000	
T	tera	10^{12}	1 000 000 000 000	trillion
G	giga	10^{9}	1 000 000 000	billion
M	mega	10^{6}	1 000 000	million
k	kilo	10^{3}	1 000	thousand
h	hecto*	10^{2}	100	hundred
da	deka*	10^{1}	10	ten
		10^{0}	1	one
d	deci*	10^{-1}	0.1	tenth
c	centi*	10^{-2}	0.01	hundredth
m	milli	10^{-3}	0.001	thousandth
µ	micro	10^{-6}	0.000 001	millionth
n	nano	10^{-9}	0.000 000 001	billionth
p	pico	10^{-12}	0.000 000 000 001	trillionth
f	femto	10^{-15}	0.000 000 000 000 001	
a	atto	10^{-18}	0.000 000 000 000 000 001	
z	zepto	10^{-21}	0.000 000 000 000 000 000 001	
y	yocto	10^{-24}	0.000 000 000 000 000 000 000 001	

* The four prefixes marked with asterisks are not recommended multiples and are thus of limited use.

Use of Symbols

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 capitalised material such as a title.

Example: ampere, watt, kelvin, meter, second, degree celsius

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

Example: A, W, K, m, s, ^{o}C

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.

Unit symbols are unaltered in the plural. However, plural unit names are used when they are required by the rules of English grammar. They are formed in the normal manner.

Example: farads is the plural of farad

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

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.

Example: N · m or N m

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

Example: newton-metre or newton metre

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: m/s, $\frac{\text{m}}{\text{s}}$ or m · s^{-1}

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.

Example: meter per second *but not:* metre/second

Unit symbols and unit names are not used together.

Example: C/kg, C · kg^{-1}, or coulomb per kilogram; *but not*: coulomb/kg;

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.

Example: cm^2, μs^{-1}

Compound prefix symbols are not permitted.

Example: ns, pF *but not:* mμs, μμF

For historical reasons, the name kilogram is used for the SI base unit of mass. However as compound prefixes are unacceptable, symbols for decimal multiples and submultiples of the unit of mass are formed by attaching prefix symbols to gram

Example: mg, milligram *but not:* μkg, microkilogram

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

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

Because it could possibly lead to confusion, mathematical operations are not applied to unit names but only to unit symbols.

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

Non-SI units commonly used with SI			
Symbol	**Non-SI Unit**	**Customary Definition**	**SI Definition**
Plane Angle			
°	degree (arc degree)	1/360 circle	π/180 radian
'	minute (arc minute)	1/60° = 1/21 600 circle	π/10 800 radian
"	second (arc second)	1/60 ' = 1/1 296 000 circle	π/648 000 radian
Time (solar)			
min	minute	60 s	60 s
h	hour	60 min	3600 s
d	day	24 h	86 400 s
a	year (seasonal)	~365.25 d	~31.6 Ms
Ma	megayear	million (10^6) years	~31.6 Ts
Ga	gigayear	billion (10^9) years	~31.6 Ps

Prefixes for binary multiples

In December 1998 the International Electrotechnical Commission (IEC, approved as an IEC International Standard names and symbols for prefixes for binary multiples for use in the fields of data processing and data transmission. The prefixes are as follows:

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

Examples and comparisons with SI prefixes

one kibibit	1 Kibit	= 2^{10} bit	= 1024 bit
one kilobit	1 kbit	= 10^3 bit	= 1000 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

The first syllable of the name of the binary-multiple prefix should be pronounced in the same way as the first syllable of the name of the corresponding SI prefix, and that the second syllable should be pronounced as "bee."

The new prefixes for binary multiples are not part of the SI Units. However, for ease of understanding and recall, they were derived from the SI prefixes for positive powers of ten. As can be seen from the above table, 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 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 of SI derived compound units

The symbol column shows what is normally seen in literature; the column to the right of the symbol column is provided to help the user rationalise combinations of units.

Derived quantity	Name	Symbol	Expressed in terms of SI base units
area	square meter	m^2	m^2
volume	cubic meter	m^3	m^3
speed, velocity	meter per second	m/s	$m \cdot s^{-1}$
acceleration	meter per second squared	m/s^2	$m \cdot s^{-2}$
density	kilogram per cubic meter	kg/m^3	$m^{-3} \cdot kg$
specific volume	cubic meter per kilogram	m^3/kg	$m^3 \cdot kg^{-1}$
current density	ampere per square meter	A/m^2	$m^{-2} \cdot A$
magnetic field strength	ampere per meter	A/m	$m^{-1} \cdot A$
luminance	candela per square meter	cd/m^2	$m^{-2} \cdot cd$
dynamic viscosity	pascal second	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
torque	newton meter	$N \cdot m$	$m^{-1} \cdot kg \cdot s^{-2}$
surface tension	newton per meter	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 meter	W/m^2	$kg \cdot s^{-3}$

Derived quantity (continued)	**Name**	**Symbol**	**In terms of base units**
heat capacity, entropy	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-2}$
specific heat capacity	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 meter kelvin	W/(m· K)	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
energy density	joule per cubic meter	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
electric field strength	volt per meter	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric charge density	coulomb per cubic meter	C/m^3	$m^{-3} \cdot s \cdot A$
electric flux density	coulomb per square meter	C/m^2	$m^{-2} \cdot s \cdot A$
permittivity	farad per meter	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
permeability	henry per meter	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 gamma 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 meter steradian	$W/(m^2 \cdot sr)$	$m^2 \cdot m^{-2} \cdot kg \cdot s^{-3} = kg \cdot s^{-3}$

Factors for Conversions to SI Units

Acceleration	1 ft/s^2 = 0.3048 m/s^2	**Magnetic**	1 gauss (G) = 10^{-4} T
	g = 9.807 m/s^2		1 maxwell (Mx) = 10^{-8} Wb
Area	1 hectares = 100 ares = 10^4 m^2		1 oersted (Oe) = 7.958 x 10^{-1} A/m
	1 acre = 4047 m^2 = 0.4047 hectares	**Power**	1 BTU/s = 1054 W
	1 circular mil = 5.067 x 10^{-10} m^2		1 cal/s = 4.184 W
	1 ft^2 = 9.290 x 10^{-2} m^2		1 horsepower (hp) = 746 W
	1 in^2 = 6.45 x 10^{-4} m^2	**Pressure**	1 atmosphere (atm) = 1.013 x 10^5 Pa
	1 mile^2 = 2.59 x 10^6 m^2		1 bar = 10^5 Pa
Density	1 lb/ft^3 = 16.02 kg/m^3		1 mm of Hg = 1 torr = 133.3 Pa
Energy	1 BTU = 1054 J		1 lb/ft^2 = 47.88 Pa
	1 calorie (cal) = 4.184 J		1 lb/in^2 (psi) = 6895 Pa
	1 electron volt (eV) = 1.602 x 10^{-19} J	**Speed**	1 rpm = 1/60 Hz = $2\pi/60$ rad/s
	1 erg = 10^{-7} J		1 ft/s (fps) = 0.3048 m/s
	1 foot pound (ft.lb) = 1.356 J		1 km/h = 0.2778 m/s
	1 kilowatt hour (kWh) = 3.60 x 10^6 J		1 mile/h(mph) = 0.44704 m/s
Force	1 dyne = 10^{-5} N	**Temperature**	$T_{Kelvin} = T_{Celsius} + 273.15$
Length	1 angstrom (Å) = 10^{-10} m		$T_{Kelvin} = (5/9)(T_{Fahrenheit} + 459.67)$
	1 ft = 0.3048 m		$T_{Celsius} = (5/9)(T_{Fahrenheit} - 32)$
	1 in = 2.54 x 10^{-2} m		$T_{Kelvin} = (5/9)\ T_{Rankine}$
	1 light year = 9.461 x 10^{15} m	**Volume**	1 ft^3 = 2.832 x 10^{-2} m^3
	1 mil = 2.54 x 10^{-5} m		1 liter = 10^{-3} m^3
	1 mile = 1609 m		1 US gallon = 3.785 liter
Mass	1 lb = 0.4536 kg		1 Imperial gallon (gal) = 4.546 litre
	1 atomic mass unit (amu) = 1.661 x 10^{-27} kg		1 in^3 = 1.639 x 10^{-5} m^3
	1 ton = 1.016 tonnes = 1016 kg		.

speed of light in vacuum (c_o) = 2.997 925 x 10^8 m s^{-1}
electric permittivity of free space (ε_o) = 8.854 x 10^{-12} F m^{-1}
magnetic permeability of free space (μ_o) = 4 x 10^{-7} H m^{-1}
Electron charge (e) = 1.60219×10^{-19} C, Electron rest mass (m) = 9.1095×10^{-31} kg
Planck's constant (h) = 6.6262×10^{-34} Js = 4.1357×10^{-15} eVs, Planck's constant ($h/2\pi$) = 1.05459×10^{-34} Js

References

1. H. P. Lehmann, X. Fuentes-Arderiu, L. F. Bertello, "GLOSSARY OF TERMS IN QUANTITIES AND UNITS IN CLINICAL CHEMISTRY ", Hypertext version January 1996 by Inge Ibsen, http://www.ifcc-iupac.suite.dk/glossary.htm#temp
2. "International System of Units from NIST", http://physics.nist.gov/cuu/Units/
3. " A Dictionary of Units of Measurement", http://www.unc.edu/~rowlett/units/index.html
4. Dennis Brownridge, "The International System of Units (SI) - A guide for teachers, students, and professionals", http://lamar.colostate.edu/~hillger/brownridge.html