National Metrology Laboratory
of South Africa

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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.

SI prefixes

The 11th CGPM (1960, Resolution 12; CR, 87) adopted a series of prefixes and prefix symbols to form the names and symbols of the decimal multiples and submultiples of SI units ranging from 10^{12} to 10^{-12}. Prefixes for 10^{-15} and 10^{-18} were added by the 12th CGPM (1964, Resolution 8; CR, 94), for 10^{15} and 10^{18} by the 15th CGPM (1975, Resolution 10; CR, 106 and *Metrologia*, 1975, **11**, 180-181), and for 10^{21}, 10^{24}, 10^{-21} and 10^{-24} by the 19th CGPM (1991, Resolution 4; CR, 185 and *Metrologia*, 1992, **29**, 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 foreseeable future. For these reasons some of the more important non-SI units are listed in the adjacent tables.

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, 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.

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

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		$m \cdot m^{-1} = 1$ (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	$cd \cdot sr$ (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	$m^2 \cdot s^{-2}$

(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, e.g. millidegree Celsius, m°C.

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 (c)	bar	$1\ bar = 0.1\ MPa = 100\ kPa = 1000\ hPa = 10^5\ Pa$
ångström	Å	$1\ Å = 0.1\ nm = 10^{-10}\ m$
barn (d)	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 (PV, 1897, 41) and are used to express areas of land.
(c) The bar and its symbol are included in Resolution 7 of the 9th CGPM (1948; CR, 70).
(d) The barn is a special unit employed in nuclear physics to express effective cross-sections.

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

Name	Symbol	Definition	Value in SI units
electronvolt (a)	eV	(b)	$1\ eV = 1.602\ 177\ 33\ (49) \times 10^{-19}\ J$
unified atomic mass unit (a)	u	(c)	$1\ u = 1.660\ 540\ 2\ (10) \times 10^{-27}\ kg$
astronomical unit (a)	ua	(d)	$1\ ua = 1.495\ 978\ 706\ 91\ (30) \times 10^{11}\ m$

(a) For the electronvolt and the unified atomic mass unit, values are quoted from CODATA Bulletin, 1986, No. 63. The value given for the astronomical unit is quoted from the IERS Conventions (1996), D.D. McCarthy ed., *IERS Technical Note* 21, Observatoire de Paris, July 1996.
(b) The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum.
(c) 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.
(d) The astronomical unit is a unit of length approximately 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 $(0.017\ 202\ 098\ 95)^2\ ua^3 \cdot d^{-2}$.

Derived CGS units with special names

Name	Symbol	Value in SI units
erg (a)	erg	$1\ erg = 10^{-7}\ J$
dyne (a)	dyn	$1\ dyn = 10^{-5}\ N$
poise (a)	P	$1\ P = 1\ dyn \cdot s/cm^2 = 0.1\ Pa \cdot s$
stokes	St	$1\ St = 1\ cm^2/s = 10^{-4}\ m^2/s$
gauss (b)	G	$1\ G \hat{=} 10^{-4}\ T$
oersted (b)	Oe	$1\ Oe \hat{=} (1000/4\pi)\ A/m$
maxwell (b)	Mx	$1\ Mx \hat{=} 10^{-8}\ Wb$
stilb (a)	sb	$1\ sb = 1\ cd/cm^2 = 10^4\ cd/m^2$
phot	ph	$1\ ph = 10^4\ lx$
gal (c)	Gal	$1\ Gal = 1\ cm/s^2 = 10^{-2}\ m/s^2$

(a) This unit and its symbol were included in Resolution 7 of the 9th CGPM (1948; CR, 70).
(b) 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. For this reason, this unit is linked to the SI unit using the mathematical symbol for "corresponds to" (≙).
(c) The gal is a special unit employed in geodesy and geophysics to express acceleration due to gravity.

SI prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	µ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	Giga	G	10^{-12}	pico	p
10^{6}	Mega	M	10^{-15}	femto	f
10^{3}	Kilo	k	10^{-18}	atto	a
10^{2}	Hecto	h	10^{-21}	zepto	z
10^{1}	Deca	da	10^{-24}	yocto	y

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 unit
dynamic viscosity	pascal second	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
moment of force	newton metre	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
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 entropy	joule per kilogram kelvin	$J/(kg \cdot K)$	$m^2 \cdot s^{-2} \cdot K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2 \cdot s^{-2}$
thermal conductivity	watt per metre kelvin	$W/(m \cdot K)$	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
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	$J/(mol \cdot K)$	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
exposure (x and γ 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	$W/(m^2 \cdot sr)$	$m^2 \cdot m^{-2} \cdot kg \cdot s^{-3} = kg \cdot s^{-3}$

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.

Non -SI units accepted for use with the International System

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

(a) The symbol of this unit is included in Resolution 7 of the 9th CGPM (1948; CR, 70).
(b) ISO 31 recommends that the degree be subdivided decimally rather than using the minute and second.
(c) This unit and the symbol 1 were adopted by CIPM in 1879 (PV, 1879, 41). The alternative symbol, L, was adopted by the 16th CGPM (1979, Resolution 6; CR, 101 and Metrologia, 1980, 16, 56-57 in order to avoid the risk of confusion between the letter l and the number 1. The present definition of the litre is given in Resolution 6 of the 12th CGPM (1964; CR, 93).
(d) This unit and its symbol were adopted by the CIPM in 1879 (PV, 1879, 41).
(e) In some English-speaking countries this unit is called "metric ton".
(f) The neper is used to express the 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.
(g) 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.
(h) In using these units it is particularly important that the quantity be specified. The unit must not be used to imply the quantity.
(i) Np is enclosed in parentheses because, although the neper is coherent with the SI, it has not yet been adopted by the CGPM.

Examples of other non-SI units

Name	Symbol	Value in SI units
curie (a)	Ci	$1\ Ci = 3.7 \times 10^{10}\ Bq$
röntgen (b)	R	$1\ R = 2.58 \times 10^{-4}\ C/kg$
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)		$1\ X\ unit = 1.002 \times 10^{-4}\ nm$
gamma (f)	γ	$1\ γ = 1\ nT = 10^{-9}\ T$
jansky	Jy	$1\ Jy = 10^{-26}\ W \cdot m^{-2} \cdot Hz^{-1}$
fermi (f)		$1\ fermi = 1\ fm = 10^{-15}\ m$
metric carat (g)		$1\ metric\ carat = 200\ mg = 2 \times 10^{-4}\ kg$
torr	Torr	1 Torr = (101 325/760) Pa
standard atmosphere	atm (h)	1 atm = 101 325 Pa
calorie	cal	(i)
micron (j)	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 (12th CGPM, 1964, Resolution 7; CR, 94).
(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 ionising 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 (CR, 89-91) for commercial dealings in diamonds, pearls and precious stones.
(h) Resolution 4 of the 10th CGPM (1954; CR, 79). 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": $1\ cal_{15} = 4.1855\ J$ (value adopted by the CIPM in 1950; PV, 1950, **22**, 79-80);
- a calorie labelled "IT" (International Table) : $1\ cal_{IT} = 4.1868\ J$ (5th International Conference on the Properties of Steam, London, 1956);
- a calorie labelled "thermochemical": $1\ cal_{th} = 4.184\ J$.

(j) The micron and its symbol, adopted by the CIPM in 1879 (PV, 1879, 41) and repeated in Resolution 7 of the 9th CGPM (1948; CR, 70) were abolished by the 13th CGPM (1967-1968, Resolution 7; CR, 105 and Metrologia, 1968, **4**, 44).

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