Appendix

Units and Conversions

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This appendix contains several tables that list the SI base units (Table A.1), define the SI base units (Table A.2), list their derived units (Table A.3), list their prefixes (Table A.4), and list their conversion units (Table A.5).

TABLE A.1 The SI Base Units

Base quantity	Name of Base Unit	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 A.2 The International Definitions of the SI Base Units[a]

unit of length
(meter)

The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second (17th CGPM,[b] 1983, Resolution 1).

Note: The original international prototype, made of platinum-iridium, is kept at the BIPM[c] under conditions specified by the 1st CGPM in 1889.

unit of mass
(kilogram)

The kilogram is the unit of mass: it is equal to the mass of the international prototype of the kilogram (3rd CGPM, (1901).

unit of time
(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 cesium-133 atom (13th CGPM, 1967, Resolution 1).

unit of electric current
(ampere)

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length (CIPM, 1946, Resolution 2 approved by the 9th CGPM, 1948).

Note: The expression "MKS unit of force" which occurs in the original text has been replaced here by "newton," a name adopted for this unit by the 9th CGPM (1948), Resolution 7.

unit of thermodynamic temperature
(kelvin)

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water (13th CGPM, 1967, Resolution 4).

The 13th CGPM (1967, Resolution 3) also decided that the unit kelvin and its symbol K should be used to express an interval or a difference in temperature.

Note: In addition to the thermodynamic temperature (symbol T), expressed in kelvin, use is also made of Celsius temperature (symbol t) defined by the equation

$$t = T - T_0$$

where $T_0 = 273.15$ K by definition. To express Celsius temperature, the unit "degree Celsius" which is equal to the unit "kelvin" is used; in this case "degree Celsius" is a special name used in place of "kelvin." An interval or difference of Celsius temperature can, however, be expressed in kelvins as well as degrees Celsius.

unit of amount of substance
(mole)

1. 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.
2. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

In the definition of the mole, it is understood that unbound atoms of carbon-12, at rest, and in their ground state, are referred to.

Note: This definition specifies at the same time the nature of the quantity whose unit is the mole.

Unit of luminous intensity
(candela)

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of (1/683) watt per steradian (16th CGPM, 1979, resolution 3).

[a] The U.S. denotes the unit of length by "meter" in place of the international usage of "meter".
[b] CGPM: Conférence Général de Poids et Mesures; CIPM: Comité International des Poids et Mesures.
[c] BIPM: Bureau International des Poids et Mesures.

TABLE A.3 SI Derived Units with Special Names[a]

Derived quantity	Name	Symbol	Expressed in Terms of Other Units	Expressed in Terms of SI Base Units
Plane angle	radian	rad		$m\ m^{-1}$
Solid angle	steradian	sr		$m^2\ m^{-2}$
Frequency	hertz	Hz		s^{-1}
Force	newton	N		$m\ kg\ s^{-2}$
Pressure, stress	pascal	Pa	$N\ m^{-2}$	$m^{-1}\ kg\ s^{-2}$
Energy, work, quantity of heat	joule	J		$m^2\ kg\ s^{-2}$
Power, radiant flux	watt	W		$m^2\ kg\ s^{-3}$
Electric charge, quantity of electricity	coulomb	C		s A
Electric potential, potential difference, electromotive force	volt	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
Capacitance	farad	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
Electric resistance	ohm	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
Electric conductance	siemens	S	A.V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
Magnetic flux	weber	Wb	V s	$m^2\ kg\ s^{-2}\ A^{-1}$
Magnetic flux density	tesla	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
Inductance	henry	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
Celsius temperature	degree Celsius	°C		K
Luminous flux	lumen	lm	cd sr	$cd\ m^2\ m^{-2} = cd$
Illuminance	lux	lx	m^{-2} cd sr	m^{-2} cd
Activity (referred to a radio nuclide)	becquerel	Bq		s^{-1}
Absorbed dose, specific energy imparted, kerma	gray	Gy	J/kg	m^2s^{-2}
Dose equivalent, ambient dose equivalent, organ equivalent dose	sievert	Sr	J/kg	m^2s^{-2}

[a] Note that when a unit is named after a person the *symbol* takes a capital letter and the *name* takes a lowercase letter.

TABLE A.4 SI Prefixes[a]

Factor	Prefix	Symbol	Factor	Prefix	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	deca	da	10^{-24}	yocto	y

[a] The 11th CGPM (1960, Resolution 12) adopted a first series of prefixes and symbols of prefixes to form the names and symbols of the decimal multiples and submultiples of SI units. Prefixes for 10^{-15} and 10^{-18} were added by the 12th CGPM (1964, Resolution 8), those for 10^{15} and 10^{18} by the 15th CGPM (1975, Resolution 10), and those for 10^{21}, 10^{24}, 10^{-21}, and 10^{-24} were proposed by the CIPM (1990) for approval by the 19th CGPM (1991).

TABLE A.5 Conversion Factors from English Measures to SI Units [a]

Unit	Equivalent
1. Acceleration	
Acceleration of free fall, standard gravity	9.806 65 m/s^2
1 ft/s^2	0.304 8 m/s^2
1 gal	0.01 m/s^2
2. Angle	
1 second (")	$4.484\ 81 \times 10^{-6}$ rad
1 minute (')	$2.908\ 9 \times 10^{4}$ rad
1 degree (°)	0.0174 532 rad
1 rad	206 264.8"
3. Area	
1 barn (b)	10^{-28} m^2
1 $in.^2$	$6.451\ 6 \times 10^{-4}$ m
1 ft^2	0.092 903 04 m^2
1 yd^2	0.836 127 36 m^2
1 are	100 m^2
1 acre [43560 (statute $ft)^2$]	4046.86 m^2
1 hectare	10 000 m^2
1 mi^2	$2.590\ 0 \times l0^6$ m^2
1 square mile (based on U.S. survey foot)	2.589 998 km^2
4. Concentration, Density, Mass Density	
1 grain/gal (U.S.)	0.017 118 kg/m^3
1 lb/ft^3	16.018 46 kg/m^3
1 lb/gal (U.S.)	119.826 4 kg/m^3
1 short ton/yd^3	1186.6 kg/m^3
1 long ton/yd^3	1328.9 kg/m^3
1 $oz(avdp)/in.^3$	1730.0 kg/m^3
1 oz(avd)/gal(U.S.)	7.489 152 kg/m^3
1 $lb/in.^3$	27 680 kg/m^3
5. Energy	
1 ft lbf	1.355 818 J
1 cal_{th} (thermochemical calorie)	4.184 J
1 cal_{15} (15°C calorie)	4.185 5 J
1 cal_{IT} [b]	4.186 8 J
1 kilocalorie (nutrition) [c]	4.186.8 J
1 watt second (W s)	1 J
1 watt hour (W h)	3600 J
1 therm (EC)	$1.055\ 06 \times 10^8$ J
1 therm (U.S.)	$1.054\ 804 \times l0^8$ J
1 ton TNT (equivalent)	4.184×10^9 J
1 BT_{th}	1 054.350 J
1 Btu_{15}	1 054.728 J
1 Btu_{ST}	1 055.055 852 62 J
1 quad (= 10^{15} Btu)	$\approx 10^{18}$ J = 1 EJ
6. Force	
1 dyne	10^{-5} N
1 ounce-force	0.278 013 9 N
1 pound-force	4.448 222 N
1 kilogram-force	9.806 65 N
1 kip (1000 lbf)	4448.222 N
1 ton-force (2000 lbf)	8.896 443 N

Unit	Equivalent
7. Fuel consumption	
1 gallon (U.S.) per horsepower hour	$1.410\,089 \times 10^{-9}$ m^3/J
1 gallon (U.S.)/mile	2.352 15 l/km
1 gallon (U.K.)/mile	2.824 81 l/km
1 mile/gallon (U.S.), mpg	0.425 144 km/l
1 mile/gallon (U.K.)	0.354 006 km/l
1 pound per horsepower	$1.689\,659 \times 10^{-7}$ kg/J
1 l/(100 km)	235.215/(mpg) (U.S.)
8. Length	
1 fermi	10^{-15} m = l fm
1 angstrom (Å)	10^{-10} m
1 microinch	2.54×10^{-8} m
1 mil	2.54×10^{-5} m
l point (pt) [0.013837 in][d]	
1 pica (12 pt)	4.217 5 mm
l inch (in.)	0.025 4 m
1 hand (4 in.)	0.101 6 m
1 foot (12 in.) (0.999998 statute ft.)	0.304 8 m
1 foot (U.S. survey)	0.304 800 6 m
1 statute foot [(1200/3937) m]	0.304 800 6 m
1 yard (yd)	0.914 4 m
1 fathom (6 ft, U.S. survey)	1.828 8 m
1 rod (16.5 statute ft)	5.029 2 m
1 chain (4 rod)	20.116 8 m
1 furlong (l0 chain)	201.168 m
1 mile (8 furlong, 5280 ft)	1609.344 m
1 statute mile (8 furlong, 5280 statute ft)	1609.347 2 m
1 nautical mile (international)[e]	1852 m
1 light year[f]	$9.640\,73 \times 10^{15}$ m
9. Light	
1 foot-candle	10.763 91 lx
1 phot	10 000 lx
1 $cd/in.^2$	1550.003 cd/m^2
1 foot-lambert	3.426 259 cd/m^2
1 lambert	3183.099 cd/m^2
1 stilb	10 000 cd/m^2
10. Mass	
1 pound (avdp.) (lb) (7000 gr)	0.453 592 37 kg
1 pound (troy) (5760 gr)	0.373 241 721 6 kg
1 grain (gr)	64.798 91 mg
1 scruple (20 gr)	1.296 0 g
1 pennyweight (24 gr)	1.555 174 g
1 dram (60 gr)	3.887 9 g
1 ounce (avdp) (437.5 gr)	28.349 52 g
1ounce (troy) (480 gr)	31.103 48 g
1 carat (metric)	0.2 g
1 stone (14 lb)	6.350 29 kg
1 slug	14.593 9 kg
1 hundredweight (long)	50.802 35 kg
1 ton (short) (2000 lb)	907.184 7 kg
1 ton (long) (2240 lb)	1016.047 kg
	1.016 047 t

TABLE A.5 Conversion Factors from English Measures to SI Units (continued)

Unit	Equivalent
Mass per Unit Length	
1 tex	10^{-6} kg/m
1 denier	$1.111\ 111 \times 10^{-7}$ kg/m
1 pound per foot	1.488 164 kg/m
1 pound per inch	17.857 97 kg/m
1 ton/mile	0.631 342 Mg/km
1 ton/1000 yd	1.111 6 kg/m
1 lb/ft	1.488 16 kg/m
Mass per Unit Area	
1 ton/mile^2	3.922 98 kg/ha
1 ton/acre	2510.71 kg/ha
1 oz/yd^2	33.905 7 g/m^2
Mass Carried × Distance (traffic factor)	
1 ton mile	1635.17 kg km
Mass carried × Distance/Volume (traffic factor)	
1 ton mile/gal (U.S.)	431.967 6 Mg km/m^3
11. Power	
1 erg/s	10^{-7} W
1 ft lbf/h	$3.766\ 161 \times 10^{-4}$ W
(1 Btu_{ST})	l.000 669 Btu_{th}
1 metric horsepower (force de cheval)	735.498 8 W
1 horsepower (550 ft lbf/s)	745.70 W
1 electric horsepower	746 W
12. Pressure, Stress	
1 standard atmosphere	101 325 Pa
1 dyne/cm^2	0.1 Pa
1 torr [(101th 325/760) Pa]	133.322 4 Pa
1 N/cm^2	10 000 Pa
1 bar	100 000 Pa
1 lbf/ft^2	47.880 26 Pa
1 lbf/in^2 (psi)	6894.8 Pa
1 kgf/cm^2	98 066.5 Pa
1 cm water (4°C)	98.063 7 Pa
1 mm of mercury (0°C)	133.322 4 Pa
1 in of water (39.2°F)	249.082 Pa
1 in of mercury (60°F)	3376.85 Pa
1 ft water (39.2°F)	2988.98 Pa
13. Thermal Quantities	
Fixed Points	
Triple point of natural water: T_{tp}	273.16 K
Zero Celsius (= $T_0 = t_{F,o}$)	273.15 K = 32°F
Temperature Conversions	
Kelvin to Rankine (T_R):	$T = (5/9)T_R$
Kelvin to Celsius	$t = T - T_0$
Kelvin to Fahrenheit	$t_F = (9/5)(T - T_0) + t_{F,0}$
Celsius to Fahrenheit	$t_F = (9/5)\ t + t_{F,0}$
[Numerically: $5(\{t_F\} + 40) = 9(\{t\} + 40)$, where $\{t\}$ and $\{t_F\}$ are the numerical values of the Celsius and Fahrenheit temperatures respectively.]	

Unit	Equivalent
Temperature Interval Conversions	
1 degree centigrade	1 degree Celsius, denoted 1°C
1°C	1 K
1°F	(1/1.8) K
1°R	(1/1.8) K
Other Thermal Quantities	
1 Btu_{th}/h	0.292 875 W
1 Btu_{IT}/h	0.293 071th 1 W
1 cal_{IT}/s	4.186 8 W
1 cal_{th}/s	4.184 W
1 cal_{IT}/(g °C)	4186.8 J/(kg K)
1 Btu ft/(ft^2 h °F)	1.730 735 W $m^{-1}K^{-1}$
1 Btu in/(ft^2 s °F)	519.220 4 W m^{-1} K^{-1}
1 clo	0.155 m^2 K/kW
1°F h ft^2/Btu	0.176 110 2 K m^2/W
1°F h ft^2/Btu·in	6.933 472 K m/W
1 Btu/lb °F ≡ 1 cal_{ST}/g °C	4186.8 J/kg.K
14. Torque, Moment of Force	
1 dyne·cm	10^{-7} N m
1 kgf·m	9.806 65 N m
1 ozf·in	0.007 061 552 N m
1 lbf·in	0.112 984 8 N m
1 lbf·ft	1.355 818 N m
15. Velocity (includes speed)	
1 foot per hour	8.466 667 × 10^{-5} m/s
1 foot per minute	0.005 08 m/s
1 knot (nautical mile per hour)	0.514 444 m/s
1 mile per hour (mi/h)	0.447 04 m/s
16. Viscosity	
1 poise	0.1 Pa s
1 ft^2/s	0.092 903 04 m^2/s
1 lb/(ft s)	1.488 164 Pa s
1 lb/(ft h)	4.133 789 × 10^{-4} Pa s
1 lbf s/ft^2	47.880 26 Pa s
1 lbf·s/in^2	6894.757 Pa s
1 rhe	10 Pa^{-1} s^{-1}
1 slug/ft s	47.880 26 Pa s
1 stokes, St	1.0 × 10^{-4} m^2/s
17. Volume (includes capacity)	
1 stere, st	1 m^3
1 liter[g]	0.001 m^3
1 ft^3	0.028 316 8 m^3
1 $in.^3$	1.638 7 × 10^{-5} m^3
1 board foot	2.359 7 × $l0^{-3}$ m^3
1 acre·foot	1233.48 m^3
1 dram (U.S. fluid)	3.696 7 × 10^{-6} m^3
1 gill (U.S.)	1.182 941 × 10^{-4} m^3
1 ounce (U.S. fluid)	2.957 353 × 10^{-5} m^3
1 teaspoon (tsp)[h]	4.9288 922 × 10^{-6} m^3
1 tablespoon (tbsp)	1.4787 676 × 10^{-5} m^3
1 pint (U.S. fluid)	4.731 765 × 10^{-4} m^3

TABLE A.5 Conversion Factors from English Measures to SI Units (continued)

Unit	Equivalent
1 quart (U.S. fluid)	$9.463\ 529 \times 10^{-4}$ m^3
1 gallon (U.S. liquid) [231 in.^{3}]	$3.785\ 412 \times 10^{-3}$ m^3
1 wine barrel (bbl) [31.5 gal (U.S.)]	0.119 240 m^3
1 barrel (petroleum, 42 gal, U.S.), bbl	0.158 987
1 ounce (U.K. fluid)	$2.841\ 3 \times l0^{-5}$ m^3
1 gill (Canada & U.K.)	$1.420\ 6 \times 10^{-4}$ m^3
1 gallon (Canada & U.K.)	$4.546\ 09 \times 10^{-3}$ m^3
	1.200 950 gal (U.S.)
1 pint (U.S. dry)	$5.506\ 105 \times 10^{-4}$ m^3
1 quart (U.S. dry)	$1.101\ 221 \times 10^{-3}$ m^3
1 gallon (U.S. dry)	$4.404\ 884 \times 10^{-3}$ m^3
1 peck	$8.809\ 768 \times 10^{-3}$ m^3
1 bushel (U.S.) [2150.42 in.^{3}]	$3.523\ 907 \times 10^{-2}$ m^3

[a] The conversion factor for a compound unit is usually not given here if it may easily be derived from simpler conversions; e.g., the conversion factors for "ft/s" to "m/s" or "ft/s^2" to "m/s^2" are not given, since they may be obtained from the conversion factor for "ft." Values are given to five or six significant digits except for exact values, which are usually indicated in bold type. A few former cgs measures are also included.

[b] The International Steam Table calorie of 1956.

[c] In practice the prefix kilo is usually omitted. The kilogram calorie or large calorie is an obsolete term for the kilocalorie which is used to express the energy content of foods.

[d] Typographer's definition, 1886.

[e] Originally, in 1929, the International nautical mile.

[f] Based on 1 day = 86,400 s and 1 Julian century = 36,525 days.

[g] Post 1964 value, SI symbol l or L. Between 1901 and 1964 the liter was defined as 1.000th 028 dm^3.

[h] Although often given, it is doubtful whether normal usage justifies this accuracy. In Europe and elsewhere the teaspoon and tablespoon are usually exactly 5 mL and 15 mL, respectively.

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