7. CONVERSION OF UNITS

The table below gives conversion factors from a variety of units to the corresponding SI unit. For each physical quantity the name is given, followed by the recommended symbol(s). Then the SI unit is given, followed by the esu, emu, Gaussian unit (Gau), atomic unit (au), and other units in common use, with their conversion factors to SI. The constant ζ which occurs in some of the electromagnetic conversion factors is the (exact) pure number $2.997\ 924\ 58 \times 10^{10} = c_0/(\text{cms}^{-1})$.

The inclusion of non-SI units in this table should not be taken to imply that their use is to be encouraged. With some exceptions, SI units are always to be preferred to non-SI units. However, since many of the units below are to be found in the scientific literature, it is convenient to tabulate their relation to the SI.

For convenience units in the esu and Gaussian systems are quoted in terms of the four dimensions *length*, *mass*, *time*, and *electric charge*, by including the franklin (Fr) as an abbreviation for the electrostatic unit of charge and $4\pi\varepsilon_0$ as a constant with dimensions $(charge)^2/(energy \times length)$. This gives each physical quantity the same dimensions in all systems, so that all conversion factors are pure numbers. The factors $4\pi4\varepsilon_0$ and the Fr may be eliminated by writing $\text{Fr} = \text{esu of charge} = \text{erg}^{1/2}\text{cm}^{1/2} = \text{cm}^{3/2}\text{g}^{1/2}\text{s}^{-1}$, $4\pi\varepsilon_0 = \varepsilon_0^{(\text{ir})} = 1\ \text{Fr}^2\ \text{erg}^{-1}\ \text{cm}^{-1} = 1$, to recover esu expressions in terms of three base units. The symbol Fr should be regarded as a compact representation of (esu of charge).

Conversion factors are either given exactly (when the = sign is used), or they are given to the approximation that the corresponding physical constants are known (when the ≈ sign is used). In the latter case the uncertainty is always less than ± 5 in the last digit quoted.

Name	Symbol	Relation to SI
Length, l		
metre (SI unit)	m	
centimetre (cgs unit)	cm	$= 10^{-2}$ m
bohr (au)	a_0, b	$= 4\pi\varepsilon_0\hbar^2/m_e e^2 \approx 5.291\ 77 \times 10^{-11}$ m
ångström	Å	$= 10^{-10}$ m
micron	μ	$= \mu\text{m} = 10^{-6}$ m
x unit	X	$\approx 1.002 \times 10^{-13}$ m
fermi	f, fm	$= \text{fm} = 10^{-15}$ m
inch	in	$= 2.54 \times 10^{-2}$ m
foot	ft	= 12 in = 0.3048 m
yard	yd	= 3 ft = 0.9144 m
mile	mi	= 1760 yd = 1609.344 m
nautical mile		= 1852 m
Area, A		
square metre (SI unit)	m^2	
barn	b	$= 10^{-28}\ \text{m}^2$
acre		$\approx 4046.856\ \text{m}^2$
are	a	$= 100\ \text{m}^2$
hectare	ha	$= 10^4\ \text{m}^2$
Volume, V		
cubic metre (SI unit)	m^3	
litre	l, L	$= \text{dm}^3 = 10^{-3}\ \text{m}^3$
lambda	λ	$= \mu\text{l} = 10^{-6}\ \text{dm}^3$
barrel (US)		$\approx 158.987\ \text{dm}^3$
gallon (US)	gal (US)	$= 3.785\ 41\ \text{dm}^3$
gallon (UK)	gal (UK)	$= 4.546\ 09\ \text{dm}^3$

Name	Symbol	Relation to SI
Mass, m		
kilogram (SI unit)	kg	
gram (cgs unit)	g	$= 10^{-3}$ kg
electron mass (au)	m_e	$\approx 9.109\,39 \times 10^{-31}$ kg
unified atomic mass unit, dalton	u, Da	$= m_a(^{12}C)/12 \approx 1.660\,540 \times 10^{-27}$ kg
tonne	t	= Mg = 10^3 kg
pound (avoirdupois)	lb	= 0.453 592 37 kg
ounce (avoirdupois)	oz	≈ 28.3495 g
ounce (troy)	oz (troy)	≈ 31.1035 g
agrain	gr	= 64.798 91 mg
Time, t		
second (SI, cgs unit)	s	
au of time	$\hbar/E_h$	$\approx 2.41888 \times 10^{-17}$ s
minute	min	= 60 s
hour	h	= 3600 s
day[a]	d	= 86 400 s
year[b]	a	≈ 31 556 952 s
svedberg	Sv	$= 10^{-13}$ s
Acceleration, a		
SI unit	$m\ s^{-2}$	$= 9.806\,65\ m\ s^{-2}$
standard accleration of free fall	g_n	
gal, galileo	Gal	$= 10^{-2}\ m\ s^{-2}$
Force, F		
newton (SI unit)[c]	N	$= kg\ m\ s^{-2}$
dyne (cgs unit)	dyn	$= g\ cm\ s^{-2} = 10^{-5}$ N
au of force	E_h/a_0	$\approx 8.238\,73 \times 10^{-8}$ N
kilogram-force	kgf	= 9.806 65 N
Energy, U		
joule (SI unit)	J	$= kg\ m^2\ s^{-2}$
erg (cgs unit)	erg	$= g\ cm^2\ s^{-2} = 10^{-7}$ J
hartree (au)	E_h	$= \hbar^2/m_e a_0^2 \approx 4.359\,75 \times 10^{-18}$ J
rydberg	Ry	$= E_h/2 \approx 2.179\,87 \times 10^{-18}$ J
electronvolt	eV	$= e \times V \approx 1.602\,18 \times 10^{-19}$ J
calorie, thermochemical	cal_{th}	= 4.184 J
calorie, international	cal_{IT}	= 4.1868 J
15°C calorie	cal_{15}	≈ 4.1855 J
litre atmosphere	1 atm	= 101.325 J
British thermal unit	Btu	= 1055.06 J
Pressure, p		
pascal (SI unit)	Pa	$= N\ m^{-2} = kg\ m^{-1}\ s^{-2}$
atmosphere	atm	= 101 325 Pa
bar	bar	$= 10^5$ Pa
torr	Torr	= (101 325/760) Pa ≈ 133.322 Pa
millimetre of mercury (conventional)	mmHg	$= 13.5951 \times 980.665 \times 10^{-2}$Pa ≈ 133.322 Pa
pounds per square inch	psi	$\approx 6.894\,757 \times 10^3$ Pa

Name	Symbol	Relation to SI
Power, P		
watt (SI unit)	W	$= \text{kg m}^2\ \text{s}^{-3}$
horse power	hp	= 745.7 W
Action, L, J (*angular momentum*)		
SI unit	J s	$= \text{kg m}^2\ \text{s}^{-1}$
cgs unit	erg s	$= 10^{-7}\text{J s}$
au of action	$\hbar$	$= h/2\pi \approx 1.054 \times 10^{-34}$ J s
Dynamic viscosity, η		
SI unit	Pa s	$= \text{kg m}^{-1}\ \text{s}^{-1}$
poise	P	$= 10^{-1}$ Pa s
centipoise	cP	= mPa s
Kinematic viscosicty, v		
SI unit	$\text{m}^2\ \text{s}^{-1}$	$= 10^{-4}\text{m}^2\ \text{s}^{-1}$
stokes	St	
Thermodynamic temperature, T		
kelvin (SI unit)	K	
degree Rankine[d]	°R	= (5/9) K
Entropy, S		
Heat capacity, C		
SI unit	J K^{-1}	
clausius	Cl	$= \text{cal}_{th}/\text{K} = 4.184\ \text{J K}^{-1}$
Molar entropy, S_m		
Molar heat capacity, C_m		
SI unit	$\text{J K}^{-1}\ \text{mol}^{-1}$	
entropy unit	e.u.	$= \text{cal}_{th}\ \text{K}^{-1}\text{mol}^{-1} = 4.184\ \text{J K}^{-1}\text{mol}^{-1}$
Molar volume, V_m		
SI unit	$\text{m}^3\ \text{mol}^{-1}$	
amagat[5]	amagat	$= V_m$ of real gas at 1 atm and 273.15 K $\approx 22.4 \times 10^{-3}\ \text{m}^3\ \text{mol}^{-1}$
Amount density, $1/V_m$		
SI unit	mol m^{-3}	
amagat[e]	amagat	$= 1/V_m$ of a real gas at 1 atm and 273.15 K $\approx 44.6\ \text{mol m}^{-3}$
Plane angle, α		
radian (SI unit)	rad	
degree	°	$= \text{rad} \times 2\pi/360 \approx (1/57.295\ 78)$ rad
minute	′	= degree/60
second	″	= degree/3600
grade	grad	$= \text{rad} \times 2\pi/400 \approx (1/63.661\ 98)$ rad

Name	Symbol	Relation to SI
Radioactivity, A		
becquerel (SI unit)	Bq	$= s^{-1}$
curie	Ci	$= 3.7 \times 10^{10}$ Bq
Absorbed dose of radiation[f]		
gray (SI unit)	Gy	$= J\ kg^{-1}$
rad	rad	= 0.01 Gy
Dose equivalent		
sievert (SI unit)	Sv	$= J\ kg^{-1}$
rem	rem	$\approx$ 0.01 Sv
Electric current, I		
ampere (SI unit)	A	
esu, Gau	$(10/\zeta)$A	$\approx 3.335\ 64 \times 10^{-10}$ A
biot (emu)	Bi	= 10 A
au	$eE_h/\hbar$	$\approx 6.623\ 62 \times 10^{-3}$ A
Electric charge, Q		
coulomb (SI unit)	C	= A s
franklin (esu, Gau)	Fr	$= (10/\zeta)C \approx 3.335\ 64 \times 10^{-10}$ C
emu (abcoulomb)		= 10 C
proton charge (au)	e	$\approx 1.602\ 18 \times 10^{-19}\ C \approx 4.803\ 21 \times 10^{-10}$ Fr
Charge density, ρ		
SI unit	$C\ m^{-3}$	
esu, Gau	$Fr\ cm^{-3}$	$= 10^7\ \zeta^{-1} C\ m^{-3} \approx 3.33564 \times 10^{-4}\ C\ m^{-3}$
au	ea_o^{-3}	$\approx 1.081\ 20 \times 10^{-12}\ C\ m^{-3}$
Electric potential, V, ϕ		
volt (SI unit)	V	$= JC^{-1} = J\ A^{-1}\ s^{-1}$
esu, Gau	$erg\ Fr^{-1}$	$= Fr\ cm^{-1}/4\pi\varepsilon_0 = 299.792\ 458$ V
'cm^{-1}'[g]	$e\ cm^{-1}/4\pi\varepsilon_0$	$\approx 1.439\ 97 \times 10^{-7}$ V
au	$e/4\pi\varepsilon_0 a_0$	$= E_h/e \approx 27.2114$ V
mean international volt		= 1.000 34 V
US international volt		= 1.000 330 V
Electric resistance, R		
ohm (SI unit)	Ω	$= V\ A^{-1} = m^2\ kg\ s^{-3}\ A^{-2}$
mean international ohm		= 1.1000 49 Ω
US international ohm		= 1.000 495 Ω
Electric field, E		
SI unit	$V\ m^{-1}$	$= J\ C^{-1}\ m^{-1}$
esu, Gau	$Fr\ cm^{-2}/4\pi\varepsilon_0$	$= 2.997\ 924\ 58 \times 10^4\ V\ m^{-1}$
'cm^{-2}'[g]	$e\ cm^{-2}/4\pi\varepsilon_0$	$\approx 1.439\ 97 \times 10^{-5}\ V\ m^{-1}$
au	$e/4\pi\varepsilon_0 a_0^2$	$= 5.142\ 21 \times 10^{11}\ V\ m^{-1}$
Electric field gradient, $E'_{\alpha\beta}$, $q_{\alpha\beta}$		
SI unit	$V\ m^{-2}$	$= J\ C^{-1}\ m^{-2}$
esu, Gau	$Fr\ cm^{-3}\ /4\pi\varepsilon_0$	$= 2.997\ 924\ 58 \times 10^6\ V\ m^{-2}$

Name	Symbol	Relation to SI
'cm^{-3}'[g]	e cm$^{-3}/4\pi\varepsilon_0$	$\approx 1.439\,97 \times 10^{-3}$ V m^{-2}
au	$e/4\pi\varepsilon_0 a_0^3$	$\approx 9.717\,36 \times 10^{21}$ V m^{-2}
Electric dipole moment, p, μ		
SI unit	C m	
esu, Gau	Fr cm	$\approx 3.335\,64 \times 10^{-12}$ C m
debye	D	$= 10^{-18}$ Fr cm $\approx 3.335\,64 \times 10^{-30}$ C m
'cm' dipole length[g]	e cm	$\approx 1.602\,18 \times 10^{-21}$ C m
au	ea_0	$\approx 8.478\,36 \times 10^{-30}$ C m
Electric quadrupole moment, $Q_{\alpha\beta}$, $\Theta_{\alpha\beta}$, eQ		
SI unit	C m^2	
esu, Gau	Fr cm^2	$\approx 3.335\,64 \times 10^{-14}$ C m^{-2}
'cm^2', quadrupole area[g]	e cm^2	$\approx 1.602\,18 \times 10^{-23}$ C m^2
au	ea_0^2	$\approx 4.486\,55 \times 10^{-40}$ C m^2
Polarizability, α		
SI unit	J^{-1} C^2 m^2	= F m^2
esu, Gau, 'cm^3' polarizability volume[g]	$4\pi\varepsilon_0$ cm^3	$\approx 1.112\,65 \times 10^{-16}$ J^{-1} C^2 m^2
'Å^3'[g]	$4\pi\varepsilon_0$ Å^3	$\approx 1.112\,65 \times 10^{-40}$ J^{-1} C^2 m^2
au	$4\pi\varepsilon_0 a_0^3$	$\approx 1.648\,78 \times 10^{-41}$ J^{-1} C^2 m^2
Electric displacement, D		
(Volume) polarization, P		
SI unit	C m^{-2}	
esu, Gau	Fr cm^{-2}	$= (10^5/\zeta)$C m^{-2} $\approx 3.33564 \times 10^{-6}$C m^{-2}

(But note: the use of the esu or Gaussian unit for electric displacment usually implies that the irrational displacement is being quoted, $D^{(\text{ir})} = 4\pi D$.)

Name	Symbol	Relation to SI
Magnetic flux density, B (*magnetic field*)		
tesla (SI unit)	T	= J A^{-1} m^{-2} = V s m^{-2} = Wb m^{-2}
gauss (emu, Gau)	G	$= 10^{-4}$ T
au	$\hbar/ea_0^2$	$\approx 2.350\,52 \times 10^5$ T
Magnetic flux, ϕ		
weber (SI unit)	Wb	= J A^{-1} = V s
maxwell (emu, Gau)	Mx	= G cm^{-2} = 10^{-8} Wb
Magnetic field, H		
(Volume) magnetization, M		
SI unit	A m^{-1}	= C s^{-1} m^{-1}
oersted (emu, Gau)	Oe	$= 10^3$ A m^{-1}

(But note: in practice the oersted, Oe, is only used as a unit for $H^{(\text{ir})} = 4\pi H$; thus when $H^{(\text{ir})} = 1$ Oe, $H = (10^3/4\pi)$ A m^{-1}.)

Name	Symbol	Relation to SI
Magnetic dipole moment, m, μ		
SI unit	$\mathrm{A\ m^2}$	$= \mathrm{J\ T^{-1}}$
emu, Gau	$\mathrm{erg\ G^{-1}}$	$= 10\ \mathrm{A\ cm^2} = 10^{-3}\ \mathrm{J\ T^{-1}}$
Bohr magneton[b]	μ_B	$= e\hbar/2m_e \approx 9.274\ 02 \times 10^{-24}\ \mathrm{J\ T^{-1}}$
au	$e\hbar/m_e$	$= 2\mu_B \approx 1.854\ 80 \times 10^{-23}\ \mathrm{J\ T^{-1}}$
nuclear magneton	μ_N	$= (m_e/m_p)\mu_B \approx 5.050\ 79 \times 10^{-27}\ \mathrm{J\ T^{-1}}$
Magnetizability, ξ		
SI unit	$\mathrm{J\ T^{-2}}$	$= \mathrm{C^2\ m^2\ kg^{-1}}$
au	$e^2a_0^2/m_e$	$\approx 7.891\ 04 \times 10^{-29}\ \mathrm{J\ T^{-2}}$
Magnetic susceptibility, χ, κ		
SI unit	1	
emu, Gau	1	
(But note: in practice susceptibilities quoted in the context of emu or Gaussian units are always values for $\chi^{(ir)} = \chi/4\pi$; thus when $\chi^{(ir)} = 10^{-6}$, $\chi = 4\pi \times 10^{6}$)		
Molar magnetic susceptibility, χ^m		
SI unit	$\mathrm{m^3\ mol^{-1}}$	
emu, Gau	$\mathrm{cm^3\ mol^{-1}}$	$= 10^{-6}\ \mathrm{cm^3\ mol^{-1}}$
(But note: in practice the units $\mathrm{cm^3\ mol^{-1}}$ usually imply that the irrational molar susceptibility is being quoted, $\chi_m^{(ir)} = \chi_m/4\pi$; for example if $\chi_m^{(ir)} = -15 \times 10^{-6}\ \mathrm{cm^3\ mol^{-1}}$, which is often written as ‘ − 15 cgs ppm’, then $\chi_m = -1.88 \times 10^{-10}\ \mathrm{m^3\ mol^{-1}}$.		

[a]Note that the day is not exactly defined in terms of the second since so-called leap-seconds are added or subtracted from the day semiannually in order to keep the annual average occurrence of midnight at 24:00 on the clock.
[b]The year is not commensurable with the date and not a constant. Prior to 1967, when the atomic standard was introduced, the tropical year 1900 served as the basis for the definition of the second. For the epoch 1900.0. it amounted to 365.242 198 79 d ≈ 31 556 925.975 s and it decreases by 0.530 seconds per century. The calendar years are exactly defined in terms of the day:

Julian year = 365.25 d
Gregorian year = 365.2425 d.

The definition in the table corresponds to the Gregorian year. This is an average based on a year of length 365 days, with leap years of 366 days; leap years are taken *either* when the year is divisible by 4 but is not divisible by 100, *or* when the year is divisible by 400.
[c]1 N is approximately the force exerted by the earth upon an apple.
[d]$T/°R = (9/5)T/K$. Also, Celsius temperature θ is related to thermodynamic temperature T by the equation:

$$\theta/°\mathrm{C} = T/\mathrm{K} - 273.15$$

Similarly Fahreheit temperature θ_F is related to Celsius temperature θ by the equation:

$$\theta_F/°\mathrm{F} = (9/5)(\theta/°\mathrm{C}) + 32$$

[e]The name ‘amagat’ is unfortunately used as a unit for both molar volume and amount density. Its value is slightly different for different gases, reflecting the deviation from ideal behaviour for the gas being considered.
[f]The unit röntgen, employed to express exposure to X or γ radiations, is equal to: $\mathrm{R} = 2.58 \times 10^{-4}\ \mathrm{C\ kg^{-1}}$.
[g]The units in quotation marks for electric potential through polarizability may be found in the literature, although they are strictly incorrect; they should be replaced in each case by the units given in the symbol column. Thus, for example, when a quadrupole moment is quoted in ‘$\mathrm{cm^2}$’, the correct unit is $e\ \mathrm{cm^2}$; and when a polarizability is quoted in ‘$\mathrm{Å^3}$’, the correct unit is $4\pi\varepsilon_0\ \mathrm{Å^3}$.
[h]The Bohr magneton μ_B is sometimes denoted BM (or B.M.), but this is not recommended.