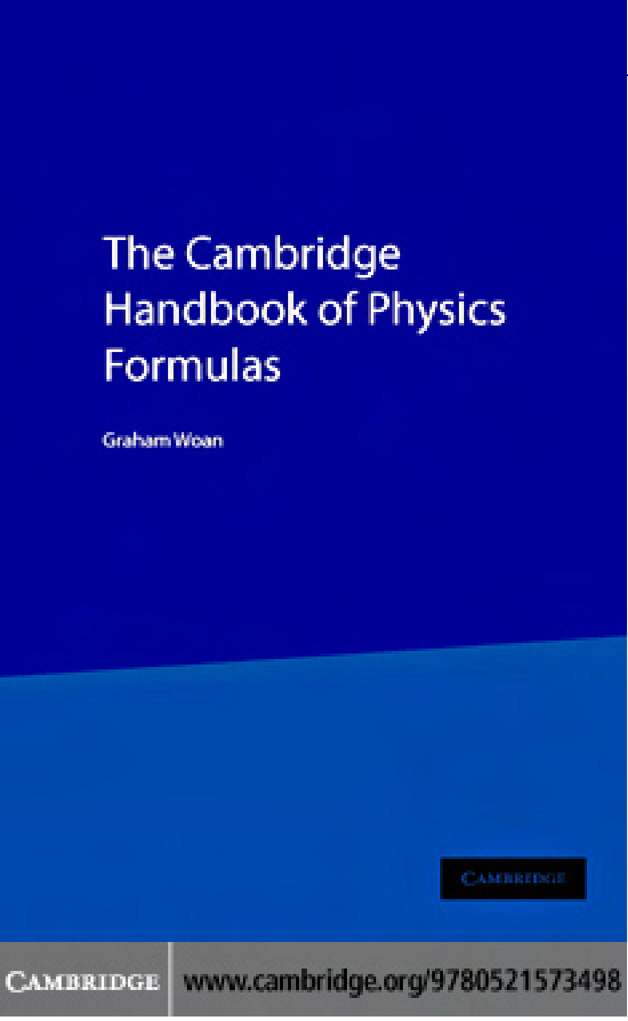
The Cambridge Handbook of Physics Formulas
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The Cambridge Handbook of Physics Formulas

The Cambridge Handbook of Physics Formulas is a quick-reference aid for students and professionals in the physical sciences and engineering. It contains more than 2 000 of the most useful formulas and equations found in undergraduate physics courses, covering mathematics, dynamics and mechanics, quantum physics, thermodynamics, solid state physics, electromagnetism, optics, and astrophysics. An exhaustive index allows the required formulas to be located swiftly and simply, and the unique tabular format crisply identifies all the variables involved.

The Cambridge Handbook of Physics Formulas comprehensively covers the major topics explored in undergraduate physics courses. It is designed to be a compact, portable, reference book suitable for everyday work, problem solving, or exam revision. All students and professionals in physics, applied mathematics, engineering, and other physical sciences will want to have this essential reference book within easy reach.

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The Cambridge Handbook of Physics Formulas

2003 Edition

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Preface

In *A Brief History of Time*, Stephen Hawking relates that he was warned against including equations in the book because "each equation... would halve the sales." Despite this dire prediction there is, for a scientific audience, some attraction in doing the exact opposite.

The reader should not be misled by this exercise. Although the equations and formulas contained here underpin a good deal of physical science they are useless unless the reader *understands* them. Learning physics is not about remembering equations, it is about appreciating the natural structures they express. Although its format should help make some topics clearer, this book is not designed to teach new physics; there are many excellent textbooks to help with that. It is intended to be useful rather than pedagogically complete, so that students can use it for revision and for structuring their knowledge *once they understand the physics*. More advanced users will benefit from having a compact, internally consistent, source of equations that can quickly deliver the relationship they require in a format that avoids the need to sift through pages of rubric.

Some difficult decisions have had to be made to achieve this. First, to be short the book only includes ideas that can be expressed succinctly in equations, without resorting to lengthy explanation. A small number of important topics are therefore absent. For example, Liouville's theorem can be algebraically succinct ($\dot{\varrho}=0$) but is meaningless unless $\dot{\varrho}$ is thoroughly (and carefully) explained. Anyone who already understands what $\dot{\varrho}$ represents will probably not need reminding that it equals zero. Second, empirical equations with numerical coefficients have been largely omitted, as have topics significantly more advanced than are found at undergraduate level. There are simply too many of these to be sensibly and confidently edited into a short handbook. Third, physical data are largely absent, although a periodic table, tables of physical constants, and data on the solar system are all included. Just a sighting of the marvellous (but dimensionally misnamed) *CRC Handbook of Chemistry and Physics* should be enough to convince the reader that a good science data book is thick.

Inevitably there is personal choice in what should or should not be included, and you may feel that an equation that meets the above criteria is missing. If this is the case, I would be delighted to hear from you so it can be considered for a subsequent edition. Contact details are at the end of this preface. Likewise, if you spot an error or an inconsistency then please let me know and I will post an erratum on the web page.

Acknowledgments This venture is founded on the generosity of colleagues in Glasgow and Cambridge whose inputs have strongly influenced the final product. The expertise of Dave Clarke, Declan Diver, Peter Duffett-Smith, Wolf-Gerrit Früh, Martin Hendry, Rico Ignace, David Ireland, John Simmons, and Harry Ward have been central to its production, as have the linguistic skills of Katie Lowe. I would also like to thank Richard Barrett, Matthew Cartmell, Steve Gull, Martin Hendry, Jim Hough, Darren McDonald, and Ken Riley who all agreed to field-test the book and gave invaluable feedback.

My greatest thanks though are to John Shakeshaft who, with remarkable knowledge and skill, worked through the entire manuscript more than once during its production and whose legendary red pen hovered over (or descended upon) every equation in the book. What errors remain are, of course, my own, but I take comfort from the fact that without John they would be much more numerous.

Contact information A website containing up-to-date information on this handbook and contact details can be found through the Cambridge University Press web pages at `us.cambridge.org` (North America) or `uk.cambridge.org` (United Kingdom), or directly at `radio.astro.gla.ac.uk/hbhome.html`.

Production notes This book was typeset by the author in LaTeX 2_ε using the CUP Times fonts. The software packages used were *WinEdt*, MiKTeX, *Mayura Draw*, *Gnuplot*, *Ghostscript*, *Ghostview*, and *Maple V*.

Comments on the 2002 edition I am grateful to all those who have suggested improvements, in particular Martin Hendry, Wolfgang Jitschin, and Joseph Katz. Although this edition contains only minor revisions to the original its production was also an opportunity to update the physical constants and periodic table entries and to reflect recent developments in cosmology.

How to use this book

The format is largely self-explanatory, but a few comments may be helpful. Although it is very tempting to flick through the pages to find what you are looking for, the best starting point is the index. I have tried to make this as extensive as possible, and many equations are indexed more than once. Equations are listed both with their equation number (in square brackets) and the page on which they can be found. The equations themselves are grouped into self-contained and boxed "panels" on the pages. Each panel represents a separate topic, and you will find descriptions of all the variables used at the right-hand side of the panel, usually adjacent to the first equation in which they are used. You should therefore not need to stray outside the panel to understand the notation. Both the panel as a whole and its individual entries may have footnotes, shown below the panel. Be aware of these, as they contain important additional information and conditions relevant to the topic.

Although the panels are self-contained they may use concepts defined elsewhere in the handbook. Often these are cross-referenced, but again the index will help you to locate them if necessary. Notations and definitions are uniform over subject areas unless stated otherwise.

Chapter 1 Units, constants, and conversions

1.1 Introduction

The determination of physical constants and the definition of the units with which they are measured is a specialised and, to many, hidden branch of science.

A quantity with dimensions is one whose value must be expressed relative to one or more standard units. In the spirit of the rest of the book, this section is based around the International System of units (SI). This system uses seven base units[1] (the number is somewhat arbitrary), such as the kilogram and the second, and defines their magnitudes in terms of physical laws or, in the case of the kilogram, an object called the "international prototype of the kilogram" kept in Paris. For convenience there are also a number of derived standards, such as the volt, which are defined as set combinations of the basic seven. Most of the physical observables we regard as being in some sense fundamental, such as the charge on an electron, are now known to a relative standard uncertainty,[2] u_{r}, of less than 10^{-7}. The least well determined is the Newtonian constant of gravitation, presently standing at a rather lamentable u_{r} of 1.5×10^{-3}, and the best is the Rydberg constant ($u_{\mathrm{r}} = 7.6 \times 10^{-12}$). The dimensionless electron g-factor, representing twice the magnetic moment of an electron measured in Bohr magnetons, is now known to a relative uncertainty of only 4.1×10^{-12}.

No matter which base units are used, physical quantities are expressed as the product of a numerical value and a unit. These two components have more-or-less equal standing and can be manipulated by following the usual rules of algebra. So, if $1 \cdot \mathrm{eV} = 160.218 \times 10^{-21} \cdot \mathrm{J}$ then $1 \cdot \mathrm{J} = [1/(160.218 \times 10^{-21})] \cdot \mathrm{eV}$. A measurement of energy, U, with joule as the unit has a numerical value of U/J. The same measurement with electron volt as the unit has a numerical value of $U/\mathrm{eV} = (U/\mathrm{J}) \cdot (\mathrm{J}/\mathrm{eV})$ and so on.

[1] The **metre** is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second. The **kilogram** is the unit of mass; it is equal to the mass of the international prototype of the kilogram. 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. 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 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length. The **kelvin**, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. 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; its symbol is "mol." 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. 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.

[2] The relative standard uncertainty in x is defined as the estimated standard deviation in x divided by the modulus of x ($x \neq 0$).

1.2 SI units

SI base units

physical quantity	*name*	*symbol*
length	metre[a]	m
mass	kilogram	kg
time interval	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

[a]Or "meter".

SI derived units

physical quantity	*name*	*symbol*	*equivalent units*
catalytic activity	katal	kat	$\mathrm{mol\,s^{-1}}$
electric capacitance	farad	F	$\mathrm{C\,V^{-1}}$
electric charge	coulomb	C	$\mathrm{A\,s}$
electric conductance	siemens	S	Ω^{-1}
electric potential difference	volt	V	$\mathrm{J\,C^{-1}}$
electric resistance	ohm	Ω	$\mathrm{V\,A^{-1}}$
energy, work, heat	joule	J	$\mathrm{N\,m}$
force	newton	N	$\mathrm{m\,kg\,s^{-2}}$
frequency	hertz	Hz	$\mathrm{s^{-1}}$
illuminance	lux	lx	$\mathrm{cd\,sr\,m^{-2}}$
inductance	henry	H	$\mathrm{V\,A^{-1}\,s}$
luminous flux	lumen	lm	$\mathrm{cd\,sr}$
magnetic flux	weber	Wb	$\mathrm{V\,s}$
magnetic flux density	tesla	T	$\mathrm{V\,s\,m^{-2}}$
plane angle	radian	rad	$\mathrm{m\,m^{-1}}$
power, radiant flux	watt	W	$\mathrm{J\,s^{-1}}$
pressure, stress	pascal	Pa	$\mathrm{N\,m^{-2}}$
radiation absorbed dose	gray	Gy	$\mathrm{J\,kg^{-1}}$
radiation dose equivalent[a]	sievert	Sv	$[\mathrm{J\,kg^{-1}}]$
radioactive activity	becquerel	Bq	$\mathrm{s^{-1}}$
solid angle	steradian	sr	$\mathrm{m^2\,m^{-2}}$
temperature[b]	degree Celsius	°C	K

[a]To distinguish it from the gray, units of $\mathrm{J\,kg^{-1}}$ should not be used for the sievert in practice.
[b]The Celsius temperature, T_C, is defined from the temperature in kelvin, T_K, by $T_C = T_K - 273.15$.

SI prefixes[a]

factor	*prefix*	*symbol*	*factor*	*prefix*	*symbol*
10^{24}	yotta	Y	10^{-24}	yocto	y
10^{21}	zetta	Z	10^{-21}	zepto	z
10^{18}	exa	E	10^{-18}	atto	a
10^{15}	peta	P	10^{-15}	femto	f
10^{12}	tera	T	10^{-12}	pico	p
10^{9}	giga	G	10^{-9}	nano	n
10^{6}	mega	M	10^{-6}	micro	μ
10^{3}	kilo	k	10^{-3}	milli	m
10^{2}	hecto	h	10^{-2}	centi	c
10^{1}	deca[b]	da	10^{-1}	deci	d

[a]The kilogram is the only SI unit with a prefix embedded in its name and symbol. For mass, the unit name "gram" and unit symbol "g" should be used with these prefixes, hence 10^{-6} kg can be written as 1 mg. Otherwise, any prefix can be applied to any SI unit.
[b]Or "deka".

Recognised non-SI units

physical quantity	*name*	*symbol*	*SI value*
area	barn	b	10^{-28} m^2
energy	electron volt	eV	$\simeq 1.602\,18 \times 10^{-19}$ J
length	ångström	Å	10^{-10} m
	fermi[a]	fm	10^{-15} m
	micron[a]	μm	10^{-6} m
plane angle	degree	$^\circ$	$(\pi/180)$ rad
	arcminute	$'$	$(\pi/10\,800)$ rad
	arcsecond	$''$	$(\pi/648\,000)$ rad
pressure	bar	bar	10^5 N m^{-2}
time	minute	min	60 s
	hour	h	3 600 s
	day	d	86 400 s
mass	unified atomic mass unit	u	$\simeq 1.660\,54 \times 10^{-27}$ kg
	tonne[a,b]	t	10^3 kg
volume	litre[c]	l, L	10^{-3} m^3

[a]These are non-SI names for SI quantities.
[b]Or "metric ton."
[c]Or "liter". The symbol "l" should be avoided.

1.3 Physical constants

The following 1998 CODATA recommended values for the fundamental physical constants can also be found on the Web at `physics.nist.gov/constants`. Detailed background information is available in *Reviews of Modern Physics*, Vol. 72, No. 2, pp. 351–495, April 2000.

The digits in parentheses represent the 1σ uncertainty in the previous two quoted digits. For example, $G = (6.673 \pm 0.010) \times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$. It is important to note that the uncertainties for many of the listed quantities are correlated, so that the uncertainty in any expression using them in combination cannot necessarily be computed from the data presented. Suitable covariance values are available in the above references.

Summary of physical constants

speed of light in vacuum[a]	c	2.997 924 58	$\times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of vacuum[b]	μ_0	4π	$\times 10^{-7}\ \mathrm{H\,m^{-1}}$
		=12.566 370 614...	$\times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of vacuum	ϵ_0	$1/(\mu_0 c^2)$	$\mathrm{F\,m^{-1}}$
		=8.854 187 817...	$\times 10^{-12}\ \mathrm{F\,m^{-1}}$
constant of gravitation[c]	G	6.673(10)	$\times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$
Planck constant	h	6.626 068 76(52)	$\times 10^{-34}\ \mathrm{J\,s}$
$h/(2\pi)$	$\hbar$	1.054 571 596(82)	$\times 10^{-34}\ \mathrm{J\,s}$
elementary charge	e	1.602 176 462(63)	$\times 10^{-19}\ \mathrm{C}$
magnetic flux quantum, $h/(2e)$	Φ_0	2.067 833 636(81)	$\times 10^{-15}\ \mathrm{Wb}$
electron volt	eV	1.602 176 462(63)	$\times 10^{-19}\ \mathrm{J}$
electron mass	m_e	9.109 381 88(72)	$\times 10^{-31}\ \mathrm{kg}$
proton mass	m_p	1.672 621 58(13)	$\times 10^{-27}\ \mathrm{kg}$
proton/electron mass ratio	$m_\mathrm{p}/m_\mathrm{e}$	1 836.152 667 5(39)	
unified atomic mass unit	u	1.660 538 73(13)	$\times 10^{-27}\ \mathrm{kg}$
fine-structure constant, $\mu_0 c e^2/(2h)$	α	7.297 352 533(27)	$\times 10^{-3}$
inverse	$1/\alpha$	137.035 999 76(50)	
Rydberg constant, $m_\mathrm{e} c \alpha^2/(2h)$	R_∞	1.097 373 156 854 9(83)	$\times 10^{7}\ \mathrm{m^{-1}}$
Avogadro constant	N_A	6.022 141 99(47)	$\times 10^{23}\ \mathrm{mol^{-1}}$
Faraday constant, $N_\mathrm{A} e$	F	9.648 534 15(39)	$\times 10^{4}\ \mathrm{C\,mol^{-1}}$
molar gas constant	R	8.314 472(15)	$\mathrm{J\,mol^{-1}\,K^{-1}}$
Boltzmann constant, R/N_A	k	1.380 650 3(24)	$\times 10^{-23}\ \mathrm{J\,K^{-1}}$
Stefan–Boltzmann constant, $\pi^2 k^4/(60\hbar^3 c^2)$	σ	5.670 400(40)	$\times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$
Bohr magneton, $e\hbar/(2m_\mathrm{e})$	μ_B	9.274 008 99(37)	$\times 10^{-24}\ \mathrm{J\,T^{-1}}$

[a] By definition, the speed of light is exact.
[b] Also exact, by definition. Alternative units are $\mathrm{N\,A^{-2}}$.
[c] The standard acceleration due to gravity, g, is defined as exactly $9.806\,65\ \mathrm{m\,s^{-2}}$.

1

General constants

speed of light in vacuum	c	2.997 924 58	$\times 10^{8}$ m s^{-1}
permeability of vacuum	μ_0	4π	$\times 10^{-7}$ H m^{-1}
		$=12.566\,370\,614\ldots$	$\times 10^{-7}$ H m^{-1}
permittivity of vacuum	ϵ_0	$1/(\mu_0 c^2)$	F m^{-1}
		$=8.854\,187\,817\ldots$	$\times 10^{-12}$ F m^{-1}
impedance of free space	Z_0	$\mu_0 c$	Ω
		$=376.730\,313\,461\ldots$	Ω
constant of gravitation	G	6.673(10)	$\times 10^{-11}$ m^3 kg^{-1} s^{-2}
Planck constant	h	6.626 068 76(52)	$\times 10^{-34}$ J s
in eV s		4.135 667 27(16)	$\times 10^{-15}$ eV s
$h/(2\pi)$	$\hbar$	1.054 571 596(82)	$\times 10^{-34}$ J s
in eV s		6.582 118 89(26)	$\times 10^{-16}$ eV s
Planck mass, $(\hbar c/G)^{1/2}$	m_{Pl}	2.176 7(16)	$\times 10^{-8}$ kg
Planck length, $\hbar/(m_{\mathrm{Pl}}c) = (\hbar G/c^3)^{1/2}$	l_{Pl}	1.616 0(12)	$\times 10^{-35}$ m
Planck time, $l_{\mathrm{Pl}}/c = (\hbar G/c^5)^{1/2}$	t_{Pl}	5.390 6(40)	$\times 10^{-44}$ s
elementary charge	e	1.602 176 462(63)	$\times 10^{-19}$ C
magnetic flux quantum, $h/(2e)$	Φ_0	2.067 833 636(81)	$\times 10^{-15}$ Wb
Josephson frequency/voltage ratio	$2e/h$	4.835 978 98(19)	$\times 10^{14}$ Hz V^{-1}
Bohr magneton, $e\hbar/(2m_{\mathrm{e}})$	μ_{B}	9.274 008 99(37)	$\times 10^{-24}$ J T^{-1}
in eV T^{-1}		5.788 381 749(43)	$\times 10^{-5}$ eV T^{-1}
μ_{B}/k		0.671 713 1(12)	K T^{-1}
nuclear magneton, $e\hbar/(2m_{\mathrm{p}})$	μ_{N}	5.050 783 17(20)	$\times 10^{-27}$ J T^{-1}
in eV T^{-1}		3.152 451 238(24)	$\times 10^{-8}$ eV T^{-1}
μ_{N}/k		3.658 263 8(64)	$\times 10^{-4}$ K T^{-1}
Zeeman splitting constant	$\mu_{\mathrm{B}}/(hc)$	46.686 452 1(19)	m^{-1} T^{-1}

Atomic constants[a]

fine-structure constant, $\mu_0 ce^2/(2h)$	α	7.297 352 533(27)	$\times 10^{-3}$
inverse	$1/\alpha$	137.035 999 76(50)	
Rydberg constant, $m_{\mathrm{e}}c\alpha^2/(2h)$	R_∞	1.097 373 156 854 9(83)	$\times 10^{7}$ m^{-1}
$R_\infty c$		3.289 841 960 368(25)	$\times 10^{15}$ Hz
$R_\infty hc$		2.179 871 90(17)	$\times 10^{-18}$ J
$R_\infty hc/e$		13.605 691 72(53)	eV
Bohr radius[b], $\alpha/(4\pi R_\infty)$	a_0	5.291 772 083(19)	$\times 10^{-11}$ m

[a]See also the Bohr model on page 95.
[b]Fixed nucleus.

Electron constants

electron mass	m_e	9.109 381 88(72)	$\times 10^{-31}$ kg
in MeV		0.510 998 902(21)	MeV
electron/proton mass ratio	m_e/m_p	5.446 170 232(12)	$\times 10^{-4}$
electron charge	$-e$	−1.602 176 462(63)	$\times 10^{-19}$ C
electron specific charge	$-e/m_e$	−1.758 820 174(71)	$\times 10^{11}$ C kg^{-1}
electron molar mass, $N_A m_e$	M_e	5.485 799 110(12)	$\times 10^{-7}$ kg mol^{-1}
Compton wavelength, $h/(m_e c)$	λ_C	2.426 310 215(18)	$\times 10^{-12}$ m
classical electron radius, $\alpha^2 a_0$	r_e	2.817 940 285(31)	$\times 10^{-15}$ m
Thomson cross section, $(8\pi/3)r_e^2$	σ_T	6.652 458 54(15)	$\times 10^{-29}$ m^2
electron magnetic moment	μ_e	−9.284 763 62(37)	$\times 10^{-24}$ J T^{-1}
in Bohr magnetons, μ_e/μ_B		−1.001 159 652 186 9(41)	
in nuclear magnetons, μ_e/μ_N		−1 838.281 966 0(39)	
electron gyromagnetic ratio, $2\|\mu_e\|/\hbar$	γ_e	1.760 859 794(71)	$\times 10^{11}$ s^{-1} T^{-1}
electron g-factor, $2\mu_e/\mu_B$	g_e	−2.002 319 304 3737(82)	

Proton constants

proton mass	m_p	1.672 621 58(13)	$\times 10^{-27}$ kg
in MeV		938.271 998(38)	MeV
proton/electron mass ratio	m_p/m_e	1 836.152 667 5(39)	
proton charge	e	1.602 176 462(63)	$\times 10^{-19}$ C
proton specific charge	e/m_p	9.578 834 08(38)	$\times 10^{7}$ C kg^{-1}
proton molar mass, $N_A m_p$	M_p	1.007 276 466 88(13)	$\times 10^{-3}$ kg mol^{-1}
proton Compton wavelength, $h/(m_p c)$	$\lambda_{C,p}$	1.321 409 847(10)	$\times 10^{-15}$ m
proton magnetic moment	μ_p	1.410 606 633(58)	$\times 10^{-26}$ J T^{-1}
in Bohr magnetons, μ_p/μ_B		1.521 032 203(15)	$\times 10^{-3}$
in nuclear magnetons, μ_p/μ_N		2.792 847 337(29)	
proton gyromagnetic ratio, $2\mu_p/\hbar$	γ_p	2.675 222 12(11)	$\times 10^{8}$ s^{-1} T^{-1}

Neutron constants

neutron mass	m_n	1.674 927 16(13)	$\times 10^{-27}$ kg
in MeV		939.565 330(38)	MeV
neutron/electron mass ratio	m_n/m_e	1 838.683 655 0(40)	
neutron/proton mass ratio	m_n/m_p	1.001 378 418 87(58)	
neutron molar mass, $N_A m_n$	M_n	1.008 664 915 78(55)	$\times 10^{-3}$ kg mol^{-1}
neutron Compton wavelength, $h/(m_n c)$	$\lambda_{C,n}$	1.319 590 898(10)	$\times 10^{-15}$ m
neutron magnetic moment	μ_n	−9.662 364 0(23)	$\times 10^{-27}$ J T^{-1}
in Bohr magnetons	μ_n/μ_B	−1.041 875 63(25)	$\times 10^{-3}$
in nuclear magnetons	μ_n/μ_N	−1.913 042 72(45)	
neutron gyromagnetic ratio, $2\|\mu_n\|/\hbar$	γ_n	1.832 471 88(44)	$\times 10^{8}$ s^{-1} T^{-1}

Muon and tau constants

muon mass	m_μ	1.883 531 09(16)	$\times10^{-28}$ kg
in MeV		105.658 356 8(52)	MeV
tau mass	m_τ	3.167 88(52)	$\times10^{-27}$ kg
in MeV		1.777 05(29)	$\times10^{3}$ MeV
muon/electron mass ratio	m_μ/m_e	206.768 262(30)	
muon charge	$-e$	−1.602 176 462(63)	$\times10^{-19}$ C
muon magnetic moment	μ_μ	−4.490 448 13(22)	$\times10^{-26}$ J T^{-1}
in Bohr magnetons, μ_μ/μ_B		4.841 970 85(15)	$\times10^{-3}$
in nuclear magnetons, μ_μ/μ_N		8.890 597 70(27)	
muon g-factor	g_μ	−2.002 331 832 0(13)	

Bulk physical constants

Avogadro constant	N_A	6.022 141 99(47)	$\times10^{23}$ mol^{-1}
atomic mass constant[a]	m_u	1.660 538 73(13)	$\times10^{-27}$ kg
in MeV		931.494 013(37)	MeV
Faraday constant	F	9.648 534 15(39)	$\times10^{4}$ C mol^{-1}
molar gas constant	R	8.314 472(15)	J mol^{-1} K^{-1}
Boltzmann constant, R/N_A	k	1.380 650 3(24)	$\times10^{-23}$ J K^{-1}
in eV K^{-1}		8.617 342(15)	$\times10^{-5}$ eV K^{-1}
molar volume (ideal gas at stp)[b]	V_m	22.413 996(39)	$\times10^{-3}$ m^3 mol^{-1}
Stefan–Boltzmann constant, $\pi^2k^4/(60\hbar^3c^2)$	σ	5.670 400(40)	$\times10^{-8}$ W m^{-2} K^{-4}
Wien's displacement law constant,[c] $b=\lambda_m T$	b	2.897 768 6(51)	$\times10^{-3}$ m K

[a]= mass of ^{12}C/12. Alternative nomenclature for the unified atomic mass unit, u.
[b]Standard temperature and pressure (stp) are $T = 273.15$ K (0°C) and $P = 101\,325$ Pa (1 standard atmosphere).
[c]See also page 121.

Mathematical constants

pi (π)	3.141 592 653 589 793 238 462 643 383 279 …
exponential constant (e)	2.718 281 828 459 045 235 360 287 471 352 …
Catalan's constant	0.915 965 594 177 219 015 054 603 514 932 …
Euler's constant[a] (γ)	0.577 215 664 901 532 860 606 512 090 082 …
Feigenbaum's constant (α)	2.502 907 875 095 892 822 283 902 873 218 …
Feigenbaum's constant (δ)	4.669 201 609 102 990 671 853 203 820 466 …
Gibbs constant	1.851 937 051 982 466 170 361 053 370 157 …
golden mean	1.618 033 988 749 894 848 204 586 834 370 …
Madelung constant[b]	1.747 564 594 633 182 190 636 212 035 544 …

[a]See also Equation (2.119).
[b]NaCl structure.

1.4 Converting between units

The following table lists common (and not so common) measures of physical quantities. The numerical values given are the SI equivalent of one unit measure of the non-SI unit. Hence 1 astronomical unit equals $149.597\,9 \times 10^9$ m. Those entries identified with a "*" in the second column represent exact conversions; so 1 abampere equals exactly 10.0 A. Note that individual entries in this list are not recorded in the index, and that values are "international" unless otherwise stated.

There is a separate section on temperature conversions after this table.

unit name	*value in SI units*	
abampere	10.0*	A
abcoulomb	10.0*	C
abfarad	1.0*	$\times 10^{9}$ F
abhenry	1.0*	$\times 10^{-9}$ H
abmho	1.0*	$\times 10^{9}$ S
abohm	1.0*	$\times 10^{-9}$ Ω
abvolt	10.0*	$\times 10^{-9}$ V
acre	4.046 856	$\times 10^{3}$ m^2
amagat (at stp)	44.614 774	mol m^{-3}
ampere hour	3.6*	$\times 10^{3}$ C
ångström	100.0*	$\times 10^{-12}$ m
apostilb	1.0*	lm m^{-2}
arcminute	290.888 2	$\times 10^{-6}$ rad
arcsecond	4.848 137	$\times 10^{-6}$ rad
are	100.0*	m^2
astronomical unit	149.597 9	$\times 10^{9}$ m
atmosphere (standard)	101.325 0*	$\times 10^{3}$ Pa
atomic mass unit	1.660 540	$\times 10^{-27}$ kg
bar	100.0*	$\times 10^{3}$ Pa
barn	100.0*	$\times 10^{-30}$ m^2
baromil	750.1	$\times 10^{-6}$ m
barrel (UK)	163.659 2	$\times 10^{-3}$ m^3
barrel (US dry)	115.627 1	$\times 10^{-3}$ m^3
barrel (US liquid)	119.240 5	$\times 10^{-3}$ m^3
barrel (US oil)	158.987 3	$\times 10^{-3}$ m^3
baud	1.0*	s^{-1}
bayre	100.0*	$\times 10^{-3}$ Pa
biot	10.0	A
bolt (US)	36.576*	m
brewster	1.0*	$\times 10^{-12}$ m^2 N^{-1}
British thermal unit	1.055 056	$\times 10^{3}$ J
bushel (UK)	36.36 872	$\times 10^{-3}$ m^3
bushel (US)	35.23 907	$\times 10^{-3}$ m^3
butt (UK)	477.339 4	$\times 10^{-3}$ m^3
cable (US)	219.456*	m
calorie	4.186 8*	J

continued on next page ...

unit name	*value in SI units*	
candle power (spherical)	4π	lm
carat (metric)	200.0*	$\times 10^{-6}$ kg
cental	45.359 237	kg
centare	1.0*	m^2
centimetre of Hg (0 °C)	1.333 222	$\times 10^{3}$ Pa
centimetre of H_2O (4 °C)	98.060 616	Pa
chain (engineers')	30.48*	m
chain (US)	20.116 8*	m
Chu	1.899 101	$\times 10^{3}$ J
clusec	1.333 224	$\times 10^{-6}$ W
cord	3.624 556	m^3
cubit	457.2*	$\times 10^{-3}$ m
cumec	1.0*	$m^3\,s^{-1}$
cup (US)	236.588 2	$\times 10^{-6}$ m^3
curie	37.0*	$\times 10^{9}$ Bq
darcy	986.923 3	$\times 10^{-15}$ m^2
day	86.4*	$\times 10^{3}$ s
day (sidereal)	86.164 09	$\times 10^{3}$ s
debye	3.335 641	$\times 10^{-30}$ C m
degree (angle)	17.453 29	$\times 10^{-3}$ rad
denier	111.111 1	$\times 10^{-9}$ $kg\,m^{-1}$
digit	19.05*	$\times 10^{-3}$ m
dioptre	1.0*	m^{-1}
Dobson unit	10.0*	$\times 10^{-6}$ m
dram (avoirdupois)	1.771 845	$\times 10^{-3}$ kg
dyne	10.0*	$\times 10^{-6}$ N
dyne centimetres	100.0*	$\times 10^{-9}$ J
electron volt	160.217 7	$\times 10^{-21}$ J
ell	1.143*	m
em	4.233 333	$\times 10^{-3}$ m
emu of capacitance	1.0*	$\times 10^{9}$ F
emu of current	10.0*	A
emu of electric potential	10.0*	$\times 10^{-9}$ V
emu of inductance	1.0*	$\times 10^{-9}$ H
emu of resistance	1.0*	$\times 10^{-9}$ Ω
Eötvös unit	1.0*	$\times 10^{-9}$ $m\,s^{-2}\,m^{-1}$
esu of capacitance	1.112 650	$\times 10^{-12}$ F
esu of current	333.564 1	$\times 10^{-12}$ A
esu of electric potential	299.792 5	V
esu of inductance	898.755 2	$\times 10^{9}$ H
esu of resistance	898.755 2	$\times 10^{9}$ Ω
erg	100.0*	$\times 10^{-9}$ J
faraday	96.485 3	$\times 10^{3}$ C
fathom	1.828 804	m
fermi	1.0*	$\times 10^{-15}$ m
Finsen unit	10.0*	$\times 10^{-6}$ $W\,m^{-2}$
firkin (UK)	40.914 81	$\times 10^{-3}$ m^3

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unit name	*value in SI units*	
firkin (US)	34.068 71	$\times 10^{-3}$ m^3
fluid ounce (UK)	28.413 08	$\times 10^{-6}$ m^3
fluid ounce (US)	29.573 53	$\times 10^{-6}$ m^3
foot	304.8*	$\times 10^{-3}$ m
foot (US survey)	304.800 6	$\times 10^{-3}$ m
foot of water (4 °C)	2.988 887	$\times 10^{3}$ Pa
footcandle	10.763 91	lx
footlambert	3.426 259	cd m^{-2}
footpoundal	42.140 11	$\times 10^{-3}$ J
footpounds (force)	1.355 818	J
fresnel	1.0*	$\times 10^{12}$ Hz
funal	1.0*	$\times 10^{3}$ N
furlong	201.168*	m
g (standard acceleration)	9.806 65*	m s^{-2}
gal	10.0*	$\times 10^{-3}$ m s^{-2}
gallon (UK)	4.546 09*	$\times 10^{-3}$ m^3
gallon (US liquid)	3.785 412	$\times 10^{-3}$ m^3
gamma	1.0*	$\times 10^{-9}$ T
gauss	100.0*	$\times 10^{-6}$ T
gilbert	795.774 7	$\times 10^{-3}$ A turn
gill (UK)	142.065 4	$\times 10^{-6}$ m^3
gill (US)	118.294 1	$\times 10^{-6}$ m^3
gon	$\pi/200$*	rad
grade	15.707 96	$\times 10^{-3}$ rad
grain	64.798 91*	$\times 10^{-6}$ kg
gram	1.0*	$\times 10^{-3}$ kg
gram-rad	100.0*	J kg^{-1}
gray	1.0*	J kg^{-1}
hand	101.6*	$\times 10^{-3}$ m
hartree	4.359 748	$\times 10^{-18}$ J
hectare	10.0*	$\times 10^{3}$ m^2
hefner	902	$\times 10^{-3}$ cd
hogshead	238.669 7	$\times 10^{-3}$ m^3
horsepower (boiler)	9.809 50	$\times 10^{3}$ W
horsepower (electric)	746*	W
horsepower (metric)	735.498 8	W
horsepower (UK)	745.699 9	W
hour	3.6*	$\times 10^{3}$ s
hour (sidereal)	3.590 170	$\times 10^{3}$ s
Hubble time	440	$\times 10^{15}$ s
Hubble distance	130	$\times 10^{24}$ m
hundredweight (UK long)	50.802 35	kg
hundredweight (US short)	45.359 24	kg
inch	25.4*	$\times 10^{-3}$ m
inch of mercury (0 °C)	3.386 389	$\times 10^{3}$ Pa
inch of water (4 °C)	249.074 0	Pa
jansky	10.0*	$\times 10^{-27}$ W m^{-2} Hz^{-1}

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unit name	*value in SI units*	
jar	10/9*	$\times 10^{-9}$ F
kayser	100.0*	m^{-1}
kilocalorie	4.186 8*	$\times 10^{3}$ J
kilogram-force	9.806 65*	N
kilowatt hour	3.6*	$\times 10^{6}$ J
knot (international)	514.444 4	$\times 10^{-3}$ m s^{-1}
lambert	$10/\pi$*	$\times 10^{3}$ cd m^{-2}
langley	41.84*	$\times 10^{3}$ J m^{-2}
langmuir	133.322 4	$\times 10^{-6}$ Pa s
league (nautical, int.)	5.556*	$\times 10^{3}$ m
league (nautical, UK)	5.559 552	$\times 10^{3}$ m
league (statute)	4.828 032	$\times 10^{3}$ m
light year	9.460 73*	$\times 10^{15}$ m
ligne	2.256*	$\times 10^{-3}$ m
line	2.116 667	$\times 10^{-3}$ m
line (magnetic flux)	10.0*	$\times 10^{-9}$ Wb
link (engineers')	304.8*	$\times 10^{-3}$ m
link (US)	201.168 0	$\times 10^{-3}$ m
litre	1.0*	$\times 10^{-3}$ m^{3}
lumen (at 555 nm)	1.470 588	$\times 10^{-3}$ W
maxwell	10.0*	$\times 10^{-9}$ Wb
mho	1.0*	S
micron	1.0*	$\times 10^{-6}$ m
mil (length)	25.4*	$\times 10^{-6}$ m
mil (volume)	1.0*	$\times 10^{-6}$ m^{3}
mile (international)	1.609 344*	$\times 10^{3}$ m
mile (nautical, int.)	1.852*	$\times 10^{3}$ m
mile (nautical, UK)	1.853 184*	$\times 10^{3}$ m
mile per hour	447.04*	$\times 10^{-3}$ m s^{-1}
milliard	1.0*	$\times 10^{9}$ m^{3}
millibar	100.0*	Pa
millimetre of Hg (0 °C)	133.322 4	Pa
minim (UK)	59.193 90	$\times 10^{-9}$ m^{3}
minim (US)	61.611 51	$\times 10^{-9}$ m^{3}
minute (angle)	290.888 2	$\times 10^{-6}$ rad
minute	60.0*	s
minute (sidereal)	59.836 17	s
month (lunar)	2.551 444	$\times 10^{6}$ s
nit	1.0*	cd m^{-2}
noggin (UK)	142.065 4	$\times 10^{-6}$ m^{3}
oersted	$1000/(4\pi)$*	A m^{-1}
ounce (avoirdupois)	28.349 52	$\times 10^{-3}$ kg
ounce (UK fluid)	28.413 07	$\times 10^{-6}$ m^{3}
ounce (US fluid)	29.573 53	$\times 10^{-6}$ m^{3}
pace	762.0*	$\times 10^{-3}$ m
parsec	30.856 78	$\times 10^{15}$ m

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unit name	*value in SI units*	
peck (UK)	9.092 18*	$\times 10^{-3}$ m^3
peck (US)	8.809 768	$\times 10^{-3}$ m^3
pennyweight (troy)	1.555 174	$\times 10^{-3}$ kg
perch	5.029 2*	m
phot	10.0*	$\times 10^{3}$ lx
pica (printers')	4.217 518	$\times 10^{-3}$ m
pint (UK)	568.261 2	$\times 10^{-6}$ m^3
pint (US dry)	550.610 5	$\times 10^{-6}$ m^3
pint (US liquid)	473.176 5	$\times 10^{-6}$ m^3
point (printers')	351.459 8*	$\times 10^{-6}$ m
poise	100.0*	$\times 10^{-3}$ Pa s
pole	5.029 2*	m
poncelot	980.665*	W
pottle	2.273 045	$\times 10^{-3}$ m^3
pound (avoirdupois)	453.592 4	$\times 10^{-3}$ kg
poundal	138.255 0	$\times 10^{-3}$ N
pound-force	4.448 222	N
promaxwell	1.0*	Wb
psi	6.894 757	$\times 10^{3}$ Pa
puncheon (UK)	317.974 6	$\times 10^{-3}$ m^3
quad	1.055 056	$\times 10^{18}$ J
quart (UK)	1.136 522	$\times 10^{-3}$ m^3
quart (US dry)	1.101 221	$\times 10^{-3}$ m^3
quart (US liquid)	946.352 9	$\times 10^{-6}$ m^3
quintal (metric)	100.0*	kg
rad	10.0*	$\times 10^{-3}$ Gy
rayleigh	$10/(4\pi)$	$\times 10^{9}$ s^{-1} m^{-2} sr^{-1}
rem	10.0*	$\times 10^{-3}$ Sv
REN	1/4 000*	S
reyn	689.5	$\times 10^{3}$ Pa s
rhe	10.0*	Pa^{-1} s^{-1}
rod	5.029 2*	m
roentgen	258.0	$\times 10^{-6}$ C kg^{-1}
rood (UK)	1.011 714	$\times 10^{3}$ m^2
rope (UK)	6.096*	m
rutherford	1.0*	$\times 10^{6}$ Bq
rydberg	2.179 874	$\times 10^{-18}$ J
scruple	1.295 978	$\times 10^{-3}$ kg
seam	290.949 8	$\times 10^{-3}$ m^3
second (angle)	4.848 137	$\times 10^{-6}$ rad
second (sidereal)	997.269 6	$\times 10^{-3}$ s
shake	100.0*	$\times 10^{-10}$ s
shed	100.0*	$\times 10^{-54}$ m^2
slug	14.593 90	kg
square degree	$(\pi/180)^{2}$*	sr
statampere	333.564 1	$\times 10^{-12}$ A
statcoulomb	333.564 1	$\times 10^{-12}$ C

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