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	$\times 10^{-7}\ \mathrm{H\ m^{-1}}$
		$=12.566\,370\,614\ldots$	$\times 10^{-7}\ \mathrm{H\ m^{-1}}$
permittivity of vacuum	ϵ_0	$1/(\mu_0 c^2)$	$\mathrm{F\ m^{-1}}$
		$=8.854\,187\,817\ldots$	$\times 10^{-12}\ \mathrm{F\ m^{-1}}$
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_p/m_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, $m_e c\alpha^2/(2h)$	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, $N_A e$	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, $e\hbar/(2m_e)$	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 $9.806\,65\ \mathrm{m\ s^{-2}}$.

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, $\mu_0 c e^2/(2h)$	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)	$\times 10^{7}$ 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, $2\lvert\mu_e\rvert/\hbar$	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, $2\lvert\mu_n\rvert/\hbar$	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)	$\times 10^{-28}$ kg
in MeV		105.658 356 8(52)	MeV
tau mass	m_τ	3.167 88(52)	$\times 10^{-27}$ kg
in MeV		1.777 05(29)	$\times 10^{3}$ MeV
muon/electron mass ratio	m_μ/m_e	206.768 262(30)	
muon charge	$-e$	−1.602 176 462(63)	$\times 10^{-19}$ C
muon magnetic moment	μ_μ	−4.490 448 13(22)	$\times 10^{-26}$ J T^{-1}
in Bohr magnetons, μ_μ/μ_B		4.841 970 85(15)	$\times 10^{-3}$
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)	$\times 10^{23}$ mol^{-1}
atomic mass constant[a]	m_u	1.660 538 73(13)	$\times 10^{-27}$ kg
in MeV		931.494 013(37)	MeV
Faraday constant	F	9.648 534 15(39)	$\times 10^{4}$ 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)	$\times 10^{-23}$ J K^{-1}
in eV K^{-1}		8.617 342(15)	$\times 10^{-5}$ eV K^{-1}
molar volume (ideal gas at stp)[b]	V_m	22.413 996(39)	$\times 10^{-3}$ m^3 mol^{-1}
Stefan–Boltzmann constant, $\pi^2 k^4/(60\hbar^3 c^2)$	σ	5.670 400(40)	$\times 10^{-8}$ W m^{-2} K^{-4}
Wien's displacement law constant,[c] $b = \lambda_m T$	b	2.897 768 6(51)	$\times 10^{-3}$ 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.