Preface

Fundamental Physical Constants: 1998

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This table gives the 1998 self-consistent set of values of the basic constants and conversion factors of physics and chemistry recommended by the Committee on Data for Science and Technology (CODATA) for international use. Further, it describes in detail the adjustment of the values of the subset of constants on which the complete 1998 set of recommended values is based. The 1998 set replaces its immediate predecessor recommended by CODATA in 1986. The new adjustment, which takes into account all of the data available through 31 December 1998, is a significant advance over its 1986 counterpart. The 1998 adjustment was carried out by P. J. Mohr and B. N. Taylor of the National Institute of Standards and Technology (NIST) under the auspices of the CODATA Task Group on Fundamental Constants. The standard uncertainties (i.e., estimated standard deviations) of the new recommended values are in most cases about 1/5 to 1/12 and in some cases 1/160 times the standard uncertainties of the corresponding 1986 values. Moreover, in almost all cases the absolute values of the differences between the 1998 values and the corresponding 1986 values are less than twice the standard uncertainties of the 1986 values.

The Task Group was established in 1969 with the aim of periodically providing the scientific and technological communities with a self-consistent set of internationally recommended values of the fundamental physical constants based on all applicable information available at a given point in time. The first set was published in 1973 and was followed by a revised set first published in 1986; the current 1998 set first appeared in 1999. In the future, the CODATA Task Group plans to take advantage of the high level of automation developed for the current set in order to issue a new set of recommended values at least every four years.

Fundamental Physical Constants — Atomic and Nuclear Constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
General				
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,533(27)\times10^{-3}$		3.7×10^{-9}
inverse fine-structure constant	α^{-1}	$137.035\,999\,76(50)$		3.7×10^{-9}
Rydberg constant $\alpha^2 m_e c/2h$	R_∞	$10\,973\,731.568\,549(83)$	m^{-1}	7.6×10^{-12}
	$R_\infty c$	$3.289\,841\,960\,368(25)\times10^{15}$	Hz	7.6×10^{-12}
	$R_\infty hc$	$2.179\,871\,90(17)\times10^{-18}$	J	7.8×10^{-8}
$R_\infty hc$ in eV		$13.605\,691\,72(53)$	eV	3.9×10^{-8}
Bohr radius $\alpha/4\pi R_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2$	a_0	$0.529\,177\,2083(19)\times10^{-10}$	m	3.7×10^{-9}
Hartree energy $e^2/4\pi\varepsilon_0 a_0 = 2R_\infty hc$ $= \alpha^2 m_e c^2$	E_h	$4.359\,743\,81(34)\times10^{-18}$	J	7.8×10^{-8}
in eV		$27.211\,3834(11)$	eV	3.9×10^{-8}
quantum of circulation	$h/2m_e$	$3.636\,947\,516(27)\times10^{-4}$	$m^2\ s^{-1}$	7.3×10^{-9}
	h/m_e	$7.273\,895\,032(53)\times10^{-4}$	$m^2\ s^{-1}$	7.3×10^{-9}
Electroweak				
Fermi coupling constant[a]	$G_F/(\hbar c)^3$	$1.166\,39(1)\times10^{-5}$	GeV^{-2}	8.6×10^{-6}
weak mixing angle[b] θ_W (on-shell scheme) $\sin^2\theta_W = s_W^2 \equiv 1-(m_W/m_Z)^2$	$\sin^2\theta_W$	$0.2224(19)$		8.7×10^{-3}
Electron, e$^-$				
electron mass	m_e	$9.109\,381\,88(72)\times10^{-31}$	kg	7.9×10^{-8}
in u, $m_e = A_r(e)$ u (electron relative atomic mass times u)		$5.485\,799\,110(12)\times10^{-4}$	u	2.1×10^{-9}
energy equivalent	$m_e c^2$	$8.187\,104\,14(64)\times10^{-14}$	J	7.9×10^{-8}
in MeV		$0.510\,998\,902(21)$	MeV	4.0×10^{-8}
electron-muon mass ratio	m_e/m_μ	$4.836\,332\,10(15)\times10^{-3}$		3.0×10^{-8}
electron-tau mass ratio	m_e/m_τ	$2.875\,55(47)\times10^{-4}$		1.6×10^{-4}
electron-proton mass ratio	m_e/m_p	$5.446\,170\,232(12)\times10^{-4}$		2.1×10^{-9}
electron-neutron mass ratio	m_e/m_n	$5.438\,673\,462(12)\times10^{-4}$		2.2×10^{-9}
electron-deuteron mass ratio	m_e/m_d	$2.724\,437\,1170(58)\times10^{-4}$		2.1×10^{-9}
electron to alpha particle mass ratio	m_e/m_α	$1.370\,933\,5611(29)\times10^{-4}$		2.1×10^{-9}
electron charge to mass quotient	$-e/m_e$	$-1.758\,820\,174(71)\times10^{11}$	$C\ kg^{-1}$	4.0×10^{-8}
electron molar mass $N_A m_e$	$M(e), M_e$	$5.485\,799\,110(12)\times10^{-7}$	$kg\ mol^{-1}$	2.1×10^{-9}
Compton wavelength $h/m_e c$	λ_C	$2.426\,310\,215(18)\times10^{-12}$	m	7.3×10^{-9}
$\lambda_C/2\pi = \alpha a_0 = \alpha^2/4\pi R_\infty$	$\bar{\lambda}_C$	$386.159\,2642(28)\times10^{-15}$	m	7.3×10^{-9}
classical electron radius $\alpha^2 a_0$	r_e	$2.817\,940\,285(31)\times10^{-15}$	m	1.1×10^{-8}
Thomson cross section $(8\pi/3)r_e^2$	σ_e	$0.665\,245\,854(15)\times10^{-28}$	m^2	2.2×10^{-8}
electron magnetic moment	μ_e	$-928.476\,362(37)\times10^{-26}$	$J\ T^{-1}$	4.0×10^{-8}
to Bohr magneton ratio	μ_e/μ_B	$-1.001\,159\,652\,1869(41)$		4.1×10^{-12}
to nuclear magneton ratio	μ_e/μ_N	$-1\,838.281\,9660(39)$		2.1×10^{-9}
electron magnetic moment anomaly $\lvert\mu_e\rvert/\mu_B - 1$	a_e	$1.159\,652\,1869(41)\times10^{-3}$		3.5×10^{-9}

Source: Peter J. Mohr and Barry N. Taylor, CODATA Recommended Values of the Fundamental Physical Constants: 1998, *Journal of Physical and Chemical Reference Data*, Vol. 28, No. 6, 1999 and *Reviews of Modern Physics*, Vol. 72, No. 2, 2000.

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Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
electron g-factor $-2(1+a_e)$	g_e	$-2.002\,319\,304\,3737(82)$		4.1×10^{-12}
electron-muon magnetic moment ratio	μ_e/μ_μ	$206.766\,9720(63)$		3.0×10^{-8}
electron-proton magnetic moment ratio	μ_e/μ_p	$-658.210\,6875(66)$		1.0×10^{-8}
electron to shielded proton magnetic moment ratio (H_2O, sphere, 25 °C)	μ_e/μ'_p	$-658.227\,5954(71)$		1.1×10^{-8}
electron-neutron magnetic moment ratio	μ_e/μ_n	$960.920\,50(23)$		2.4×10^{-7}
electron-deuteron magnetic moment ratio	μ_e/μ_d	$-2\,143.923\,498(23)$		1.1×10^{-8}
electron to shielded helion[c] magnetic moment ratio (gas, sphere, 25 °C)	μ_e/μ'_h	$864.058\,255(10)$		1.2×10^{-8}
electron gyromagnetic ratio $2\|\mu_e\|/\hbar$	γ_e	$1.760\,859\,794(71)\times10^{11}$	$s^{-1}\,T^{-1}$	4.0×10^{-8}
	$\gamma_e/2\pi$	$28\,024.9540(11)$	MHz T^{-1}	4.0×10^{-8}
		Muon, μ^-		
muon mass	m_μ	$1.883\,531\,09(16)\times10^{-28}$	kg	8.4×10^{-8}
in u, $m_\mu = A_r(\mu)$ u (muon relative atomic mass times u)		$0.113\,428\,9168(34)$	u	3.0×10^{-8}
energy equivalent	$m_\mu c^2$	$1.692\,833\,32(14)\times10^{-11}$	J	8.4×10^{-8}
in MeV		$105.658\,3568(52)$	MeV	4.9×10^{-8}
muon-electron mass ratio	m_μ/m_e	$206.768\,2657(63)$		3.0×10^{-8}
muon-tau mass ratio	m_μ/m_τ	$5.945\,72(97)\times10^{-2}$		1.6×10^{-4}
muon-proton mass ratio	m_μ/m_p	$0.112\,609\,5173(34)$		3.0×10^{-8}
muon-neutron mass ratio	m_μ/m_n	$0.112\,454\,5079(34)$		3.0×10^{-8}
muon molar mass $N_A m_\mu$	$M(\mu)$, M_μ	$0.113\,428\,9168(34)\times10^{-3}$	kg mol^{-1}	3.0×10^{-8}
muon Compton wavelength $h/m_\mu c$	$\lambda_{C,\mu}$	$11.734\,441\,97(35)\times10^{-15}$	m	2.9×10^{-8}
$\lambda_{C,\mu}/2\pi$	$\bar{\lambda}_{C,\mu}$	$1.867\,594\,444(55)\times10^{-15}$	m	2.9×10^{-8}
muon magnetic moment	μ_μ	$-4.490\,448\,13(22)\times10^{-26}$	J T^{-1}	4.9×10^{-8}
to Bohr magneton ratio	μ_μ/μ_B	$-4.841\,970\,85(15)\times10^{-3}$		3.0×10^{-8}
to nuclear magneton ratio	μ_μ/μ_N	$-8.890\,597\,70(27)$		3.0×10^{-8}
muon magnetic moment anomaly $\|\mu_\mu\|/(e\hbar/2m_\mu)-1$	a_μ	$1.165\,916\,02(64)\times10^{-3}$		5.5×10^{-7}
muon g-factor $-2(1+a_\mu)$	g_μ	$-2.002\,331\,8320(13)$		6.4×10^{-10}
muon-proton magnetic moment ratio	μ_μ/μ_p	$-3.183\,345\,39(10)$		3.2×10^{-8}
		Tau, τ^-		
tau mass[d]	m_τ	$3.167\,88(52)\times10^{-27}$	kg	1.6×10^{-4}
in u, $m_\tau = A_r(\tau)$ u (tau				

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Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
relative atomic mass times u)		1.907 74(31)	u	1.6×10^{-4}
energy equivalent	$m_\tau c^2$	$2.847\,15(46) \times 10^{-10}$	J	1.6×10^{-4}
in MeV		1 777.05(29)	MeV	1.6×10^{-4}
tau-electron mass ratio	m_τ/m_e	3 477.60(57)		1.6×10^{-4}
tau-muon mass ratio	m_τ/m_μ	16.8188(27)		1.6×10^{-4}
tau-proton mass ratio	m_τ/m_p	1.893 96(31)		1.6×10^{-4}
tau-neutron mass ratio	m_τ/m_n	1.891 35(31)		1.6×10^{-4}
tau molar mass $N_A m_\tau$	$M(\tau)$, M_τ	$1.907\,74(31) \times 10^{-3}$	kg mol^{-1}	1.6×10^{-4}
tau Compton wavelength $h/m_\tau c$	$\lambda_{C,\tau}$	$0.697\,70(11) \times 10^{-15}$	m	1.6×10^{-4}
$\lambda_{C,\tau}/2\pi$	$\bar{\lambda}_{C,\tau}$	$0.111\,042(18) \times 10^{-15}$	m	1.6×10^{-4}
		Proton, p		
proton mass	m_p	$1.672\,621\,58(13) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_p = A_r(p)$ u (proton relative atomic mass times u)		1.007 276 466 88(13)	u	1.3×10^{-10}
energy equivalent	$m_p c^2$	$1.503\,277\,31(12) \times 10^{-10}$	J	7.9×10^{-8}
in MeV		938.271 998(38)	MeV	4.0×10^{-8}
proton-electron mass ratio	m_p/m_e	1 836.152 6675(39)		2.1×10^{-9}
proton-muon mass ratio	m_p/m_μ	8.880 244 08(27)		3.0×10^{-8}
proton-tau mass ratio	m_p/m_τ	0.527 994(86)		1.6×10^{-4}
proton-neutron mass ratio	m_p/m_n	0.998 623 478 55(58)		5.8×10^{-10}
proton charge to mass quotient	e/m_p	$9.578\,834\,08(38) \times 10^{7}$	C kg^{-1}	4.0×10^{-8}
proton molar mass $N_A m_p$	$M(p)$, M_p	$1.007\,276\,466\,88(13) \times 10^{-3}$	kg mol^{-1}	1.3×10^{-10}
proton Compton wavelength $h/m_p c$	$\lambda_{C,p}$	$1.321\,409\,847(10) \times 10^{-15}$	m	7.6×10^{-9}
$\lambda_{C,p}/2\pi$	$\bar{\lambda}_{C,p}$	$0.210\,308\,9089(16) \times 10^{-15}$	m	7.6×10^{-9}
proton magnetic moment	μ_p	$1.410\,606\,633(58) \times 10^{-26}$	J T^{-1}	4.1×10^{-8}
to Bohr magneton ratio	μ_p/μ_B	$1.521\,032\,203(15) \times 10^{-3}$		1.0×10^{-8}
to nuclear magneton ratio	μ_p/μ_N	2.792 847 337(29)		1.0×10^{-8}
proton g-factor $2\mu_p/\mu_N$	g_p	5.585 694 675(57)		1.0×10^{-8}
proton-neutron magnetic moment ratio	μ_p/μ_n	−1.459 898 05(34)		2.4×10^{-7}
shielded proton magnetic moment (H_2O, sphere, 25 °C)	μ'_p	$1.410\,570\,399(59) \times 10^{-26}$	J T^{-1}	4.2×10^{-8}
to Bohr magneton ratio	μ'_p/μ_B	$1.520\,993\,132(16) \times 10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ'_p/μ_N	2.792 775 597(31)		1.1×10^{-8}
proton magnetic shielding correction $1 - \mu'_p/\mu_p$ (H_2O, sphere, 25 °C)	σ'_p	$25.687(15) \times 10^{-6}$		5.7×10^{-4}
proton gyromagnetic ratio $2\mu_p/\hbar$	γ_p	$2.675\,222\,12(11) \times 10^{8}$	s^{-1} T^{-1}	4.1×10^{-8}
	$\gamma_p/2\pi$	42.577 4825(18)	MHz T^{-1}	4.1×10^{-8}
shielded proton gyromagnetic ratio $2\mu'_p/\hbar$	γ'_p	$2.675\,153\,41(11) \times 10^{8}$	s^{-1} T^{-1}	4.2×10^{-8}

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Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
(H_2O, sphere, 25 °C)				
	$\gamma'_p/2\pi$	42.576 3888(18)	MHz T^{-1}	4.2×10^{-8}
		Neutron, n		
neutron mass	m_n	$1.674\,927\,16(13) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_n = A_r(n)$ u (neutron relative atomic mass times u)		1.008 664 915 78(55)	u	5.4×10^{-10}
energy equivalent	$m_n c^2$	$1.505\,349\,46(12) \times 10^{-10}$	J	7.9×10^{-8}
in MeV		939.565 330(38)	MeV	4.0×10^{-8}
neutron-electron mass ratio	m_n/m_e	1 838.683 6550(40)		2.2×10^{-9}
neutron-muon mass ratio	m_n/m_μ	8.892 484 78(27)		3.0×10^{-8}
neutron-tau mass ratio	m_n/m_τ	0.528 722(86)		1.6×10^{-4}
neutron-proton mass ratio	m_n/m_p	1.001 378 418 87(58)		5.8×10^{-10}
neutron molar mass $N_A m_n$	$M(n)$, M_n	$1.008\,664\,915\,78(55) \times 10^{-3}$	kg mol^{-1}	5.4×10^{-10}
neutron Compton wavelength $h/m_n c$	$\lambda_{C,n}$	$1.319\,590\,898(10) \times 10^{-15}$	m	7.6×10^{-9}
$\lambda_{C,n}/2\pi$	$\bar{\lambda}_{C,n}$	$0.210\,019\,4142(16) \times 10^{-15}$	m	7.6×10^{-9}
neutron magnetic moment	μ_n	$-0.966\,236\,40(23) \times 10^{-26}$	J T^{-1}	2.4×10^{-7}
to Bohr magneton ratio	μ_n/μ_B	$-1.041\,875\,63(25) \times 10^{-3}$		2.4×10^{-7}
to nuclear magneton ratio	μ_n/μ_N	−1.913 042 72(45)		2.4×10^{-7}
neutron g-factor $2\mu_n/\mu_N$	g_n	−3.826 085 45(90)		2.4×10^{-7}
neutron-electron magnetic moment ratio	μ_n/μ_e	$1.040\,668\,82(25) \times 10^{-3}$		2.4×10^{-7}
neutron-proton magnetic moment ratio	μ_n/μ_p	−0.684 979 34(16)		2.4×10^{-7}
neutron to shielded proton magnetic moment ratio (H_2O, sphere, 25 °C)	μ_n/μ'_p	−0.684 996 94(16)		2.4×10^{-7}
neutron gyromagnetic ratio $2\lvert\mu_n\rvert/\hbar$	γ_n	$1.832\,471\,88(44) \times 10^{8}$	s^{-1} T^{-1}	2.4×10^{-7}
	$\gamma_n/2\pi$	29.164 6958(70)	MHz T^{-1}	2.4×10^{-7}
		Deuteron, d		
deuteron mass	m_d	$3.343\,583\,09(26) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_d = A_r(d)$ u (deuteron relative atomic mass times u)		2.013 553 212 71(35)	u	1.7×10^{-10}
energy equivalent	$m_d c^2$	$3.005\,062\,62(24) \times 10^{-10}$	J	7.9×10^{-8}
in MeV		1 875.612 762(75)	MeV	4.0×10^{-8}
deuteron-electron mass ratio	m_d/m_e	3 670.482 9550(78)		2.1×10^{-9}
deuteron-proton mass ratio	m_d/m_p	1.999 007 500 83(41)		2.0×10^{-10}
deuteron molar mass $N_A m_d$	$M(d)$, M_d	$2.013\,553\,212\,71(35) \times 10^{-3}$	kg mol^{-1}	1.7×10^{-10}
deuteron magnetic moment	μ_d	$0.433\,073\,457(18) \times 10^{-26}$	J T^{-1}	4.2×10^{-8}
to Bohr magneton ratio	μ_d/μ_B	$0.466\,975\,4556(50) \times 10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ_d/μ_N	0.857 438 2284(94)		1.1×10^{-8}

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deuteron-electron magnetic moment ratio	μ_d/μ_e	$-4.664\,345\,537(50) \times 10^{-4}$		1.1×10^{-8}
deuteron-proton magnetic moment ratio	μ_d/μ_p	$0.307\,012\,2083(45)$		1.5×10^{-8}
deuteron-neutron magnetic moment ratio	μ_d/μ_n	$-0.448\,206\,52(11)$		2.4×10^{-7}
		Helion, h		
helion mass[c]	m_h	$5.006\,411\,74(39) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_h = A_r(h)$ u (helion relative atomic mass times u)		$3.014\,932\,234\,69(86)$	u	2.8×10^{-10}
energy equivalent	$m_h c^2$	$4.499\,538\,48(35) \times 10^{-10}$	J	7.9×10^{-8}
in MeV		$2\,808.391\,32(11)$	MeV	4.0×10^{-8}
helion-electron mass ratio	m_h/m_e	$5\,495.885\,238(12)$		2.1×10^{-9}
helion-proton mass ratio	m_h/m_p	$2.993\,152\,658\,50(93)$		3.1×10^{-10}
helion molar mass $N_A m_h$	$M(h)$, M_h	$3.014\,932\,234\,69(86) \times 10^{-3}$	kg mol^{-1}	2.8×10^{-10}
shielded helion magnetic moment (gas, sphere, 25 °C)	μ'_h	$-1.074\,552\,967(45) \times 10^{-26}$	J T^{-1}	4.2×10^{-8}
to Bohr magneton ratio	μ'_h/μ_B	$-1.158\,671\,474(14) \times 10^{-3}$		1.2×10^{-8}
to nuclear magneton ratio	μ'_h/μ_N	$-2.127\,497\,718(25)$		1.2×10^{-8}
shielded helion to proton magnetic moment ratio (gas, sphere, 25 °C)	μ'_h/μ_p	$-0.761\,766\,563(12)$		1.5×10^{-8}
shielded helion to shielded proton magnetic moment ratio (gas/H_2O, spheres, 25 °C)	μ'_h/μ'_p	$-0.761\,786\,1313(33)$		4.3×10^{-9}
shielded helion gyromagnetic ratio $2\lvert\mu'_h\rvert/\hbar$ (gas, sphere, 25 °C)	γ'_h	$2.037\,894\,764(85) \times 10^{8}$	s^{-1} T^{-1}	4.2×10^{-8}
	$\gamma'_h/2\pi$	$32.434\,1025(14)$	MHz T^{-1}	4.2×10^{-8}
		Alpha particle, α		
alpha particle mass	m_α	$6.644\,655\,98(52) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_\alpha = A_r(\alpha)$ u (alpha particle relative atomic mass times u)		$4.001\,506\,1747(10)$	u	2.5×10^{-10}
energy equivalent	$m_\alpha c^2$	$5.971\,918\,97(47) \times 10^{-10}$	J	7.9×10^{-8}
in MeV		$3\,727.379\,04(15)$	MeV	4.0×10^{-8}
alpha particle to electron mass ratio	m_α/m_e	$7\,294.299\,508(16)$		2.1×10^{-9}
alpha particle to proton mass ratio	m_α/m_p	$3.972\,599\,6846(11)$		2.8×10^{-10}
alpha particle molar mass $N_A m_\alpha$	$M(\alpha)$, M_α	$4.001\,506\,1747(10) \times 10^{-3}$	kg mol^{-1}	2.5×10^{-10}

[a] Value recommended by the Particle Data Group, Caso et al., Eur. Phys. J. C **3**(1-4), 1-794 (1998).

[b] Based on the ratio of the masses of the W and Z bosons m_W/m_Z recommended by the Particle Data Group (Caso et al., 1998). The value for $\sin^2\theta_W$ they recommend, which is based on a particular variant of the modified minimal subtraction ($\overline{\mathrm{MS}}$) scheme, is $\sin^2\hat{\theta}_W(M_Z) = 0.231\,24(24)$.

[c] The helion, symbol h, is the nucleus of the ^{3}He atom.

[d] This and all other values involving m_τ are based on the value of $m_\tau c^2$ in MeV recommended by the Particle Data Group, Caso et al., Eur. Phys. J. C **3**(1-4), 1-794 (1998), but with a standard uncertainty of 0.29 MeV rather than the quoted uncertainty of −0.26 MeV, +0.29 MeV.

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