

1. PHYSICAL CONSTANTS

Table 1.1. Reviewed 2000 by P.J. Mohr and B.N. Taylor (NIST). Based mainly on the “CODATA Recommended Values of the Fundamental Physical Constants: 1998” by P.J. Mohr and B.N. Taylor, *J. Phys. Chem. Ref. Data* **28**, 1713 (1999) and *Rev. Mod. Phys.* **72**, 351 (2000). The last group of constants (beginning with the Fermi coupling constant) comes from the Particle Data Group. The figures in parentheses after the values give the 1-standard-deviation uncertainties in the last digits; the corresponding uncertainties in parts per billion (ppb) are given in the last column. This set of constants (aside from the last group) is recommended for international use by CODATA (the Committee on Data for Science and Technology). The full 1998 CODATA set of constants may be found at <http://physics.nist.gov/constants>

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	299 792 458 m s ⁻¹	exact*
Planck constant	h	6.626 068 76(52) × 10 ⁻³⁴ J s	78
Planck constant, reduced	$\hbar \equiv h/2\pi$	1.054 571 596(82) × 10 ⁻³⁴ J s = 6.582 118 89(26) × 10 ⁻²² MeV s	78 39
electron charge magnitude	e	1.602 176 462(63) × 10 ⁻¹⁹ C = 4.803 204 20(19) × 10 ⁻¹⁰ esu	39, 39
conversion constant	$\hbar c$	197.326 960 2(77) MeV fm	39
conversion constant	$(\hbar c)^2$	0.389 379 292(30) GeV ² mbarn	78
electron mass	m_e	0.510 998 902(21) MeV/c ² = 9.109 381 88(72) × 10 ⁻³¹ kg	40, 79
proton mass	m_p	938.271 998(38) MeV/c ² = 1.672 621 58(13) × 10 ⁻²⁷ kg = 1.007 276 466 88(13) u = 1836.152 667 5(39) m_e	40, 79 0.13, 2.1
deuteron mass	m_d	1875.612 762(75) MeV/c ²	40
unified atomic mass unit (u)	(mass ¹² C atom)/12 = (1 g)/(N _A mol)	931.494 013(37) MeV/c ² = 1.660 538 73(13) × 10 ⁻²⁷ kg	40, 79
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	8.854 187 817 ... × 10 ⁻¹² F m ⁻¹	exact
permeability of free space	μ_0	4π × 10 ⁻⁷ N A ⁻² = 12.566 370 614 ... × 10 ⁻⁷ N A ⁻²	exact
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	7.297 352 533(27) × 10 ⁻³ = 1/137.035 999 76(50) [†]	3.7, 3.7
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 285(31) × 10 ⁻¹⁵ m	11
(e ⁻ Compton wavelength)/2π	$\lambda_e = \hbar/m_e c = r_e \alpha^{-1}$	3.861 592 642(28) × 10 ⁻¹³ m	7.3
Bohr radius ($m_{\text{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0 \hbar^2 / m_e e^2 = r_e \alpha^{-2}$	0.529 177 208 3(19) × 10 ⁻¹⁰ m	3.7
wavelength of 1 eV/c particle	$\hbar c/e$	1.239 841 857(49) × 10 ⁻⁶ m	39
Rydberg energy	$\hbar c R_\infty = m_e e^4 / 2(4\pi\epsilon_0)^2 \hbar^2 = m_e c^2 \alpha^2 / 2$	13.605 691 72(53) eV	39
Thomson cross section	$\sigma_T = 8\pi r_e^2 / 3$	0.665 245 854(15) barn	22
Bohr magneton	$\mu_B = e\hbar/2m_e$	5.788 381 749(43) × 10 ⁻¹¹ MeV T ⁻¹	7.3
nuclear magneton	$\mu_N = e\hbar/2m_p$	3.152 451 238(24) × 10 ⁻¹⁴ MeV T ⁻¹	7.6
electron cyclotron freq./field	$\omega_{\text{cycl}}^e / B = e/m_e$	1.758 820 174(71) × 10 ¹¹ rad s ⁻¹ T ⁻¹	40
proton cyclotron freq./field	$\omega_{\text{cycl}}^p / B = e/m_p$	9.578 834 08(38) × 10 ⁷ rad s ⁻¹ T ⁻¹	40
gravitational constant [‡]	G_N	6.673(10) × 10 ⁻¹¹ m ³ kg ⁻¹ s ⁻² = 6.707(10) × 10 ⁻³⁹ $\hbar c$ (GeV/c ²) ⁻²	1.5 × 10 ⁶ 1.5 × 10 ⁶
standard grav. accel., sea level	g_n	9.806 65 m s ⁻²	exact
Avogadro constant	N_A	6.022 141 99(47) × 10 ²³ mol ⁻¹	79
Boltzmann constant	k	1.380 650 3(24) × 10 ⁻²³ J K ⁻¹ = 8.617 342(15) × 10 ⁻⁵ eV K ⁻¹	1700 1700
molar volume, ideal gas at STP	$N_A k(273.15 \text{ K}) / (101 325 \text{ Pa})$	22.413 996(39) × 10 ⁻³ m ³ mol ⁻¹	1700
Wien displacement law constant	$b = \lambda_{\text{max}} T$	2.897 768 6(51) × 10 ⁻³ m K	1700
Stefan-Boltzmann constant	$\sigma = \pi^2 k^4 / 60 \hbar^3 c^2$	5.670 400(40) × 10 ⁻⁸ W m ⁻² K ⁻⁴	7000
Fermi coupling constant**	$G_F / (\hbar c)^3$	1.166 39(1) × 10 ⁻⁵ GeV ⁻²	9000
weak-mixing angle	$\sin^2 \hat{\theta}(M_Z) (\overline{\text{MS}})$	0.23117(16) ^{††}	7 × 10 ⁵
W [±] boson mass	m_W	80.419(56) GeV/c ²	7 × 10 ⁵
Z ⁰ boson mass	m_Z	91.1882(22) GeV/c ²	2.4 × 10 ⁴
strong coupling constant	$\alpha_s(m_Z)$	0.1185(20)	1.7 × 10 ⁷
$\pi = 3.141 592 653 589 793 238$		$e = 2.718 281 828 459 045 235$	$\gamma = 0.577 215 664 901 532 861$
1 in ≡ 0.0254 m 1 G ≡ 10 ⁻⁴ T		1 eV = 1.602 176 462(63) × 10 ⁻¹⁹ J	kT at 300 K = [38.681 686(67)] ⁻¹ eV
1 Å ≡ 0.1 nm 1 dyne ≡ 10 ⁻⁵ N		1 eV/c ² = 1.782 661 731(70) × 10 ⁻³⁶ kg	0 °C ≡ 273.15 K
1 barn ≡ 10 ⁻²⁸ m ² 1 erg ≡ 10 ⁻⁷ J		2.997 924 58 × 10 ⁹ esu = 1 C	1 atmosphere ≡ 760 Torr ≡ 101 325 Pa

* 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.

† At $Q^2 = 0$. At $Q^2 \approx m_W^2$ the value is approximately 1/128.

‡ Absolute lab measurements of G_N have been made only on scales of 1 mm to 1 m.

** See the discussion in Sec. 10, “Electroweak model and constraints on new physics.”

†† The corresponding $\sin^2 \theta$ for the effective angle is 0.23147(16).