1. Physical Constants (a major revision)

Table 1.1. Revised 2019 by C.G. Wohl (LBNL). Reviewed by P.J. Mohr and D.B. Newell (NIST). Mainly from "CODATA Recommended Values of the Fundamental Physical Constants: 2018," E. Tiesinga, D.B. Newell, P.J. Mohr, and B.N. Taylor, NIST SP961 (May 2019). The electron charge magnitude e, and the Planck, Boltzmann, and Avogadro constants h, k, and N_A, now join c as having defined values; the free-space permittivity and permeability constants ϵ_0 and μ_0 are no longer exact. These changes affect practically everything else in the Table. Figures in parentheses after the values are the 1-standard-deviation uncertainties in the last digits; the fractional uncertainties in parts per 10^9 (ppb) are in the last column. The full 2018 CODATA Committee on Data for Science and Technology set of constants are found at `https://physics.nist.gov/constants`. The last set of constants (beginning with the Fermi coupling constant) comes from the Particle Data Group. See also "The International System of Units (SI)," 9th ed. (2019) of the International Bureau of Weights and Measures (BIPM), `https://www.bipm.org/utils/common/pdf/si-brochure/SI-Brochure-9-EN.pdf`.

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	$299\ 792\ 458$ m s^{-1}	exact
Planck constant	h	$6.626\ 070\ 15\times10^{-34}$ J s (or J/Hz)$^\sharp$	exact
Planck constant, reduced	$\hbar \equiv h/2\pi$	$1.054\ 571\ 817\ldots \times 10^{-34}$ J s	exact*
		$= 6.582\ 119\ 569\ldots \times 10^{-22}$ MeV s	exact*
electron charge magnitude	e	$1.602\ 176\ 634\times10^{-19}$ C	exact
conversion constant	$\hbar c$	$197.326\ 980\ 4\ldots$ MeV fm	exact*
conversion constant	$(\hbar c)^2$	$0.389\ 379\ 372\ 1\ldots$ GeV^2 mbarn	exact*
electron mass	m_e	$0.510\ 998\ 950\ 00(15)$ MeV/c^2 $= 9.109\ 383\ 7015(28)\times10^{-31}$ kg	0.30
proton mass	m_p	$938.272\ 088\ 16(29)$ MeV/c^2 $= 1.672\ 621\ 923\ 69(51)\times10^{-27}$ kg	0.31
		$= 1.007\ 276\ 466\ 621(53)$ u $= 1836.152\ 673\ 43(11)\ m_e$	0.053, 0.060
neutron mass	m_n	$939.565\ 420\ 52(54)$ MeV/c^2 $= 1.008\ 664\ 915\ 95(49)$ u	0.57, 0.48
deuteron mass	m_d	$1875.612\ 942\ 57(57)$ MeV/c^2	0.30
unified atomic mass unit**	$u = (\text{mass } ^{12}\text{C atom})/12$	$931.494\ 102\ 42(28)$ MeV/c^2 $= 1.660\ 539\ 066\ 60(50)\times10^{-27}$ kg	0.30
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	$8.854\ 187\ 8128(13)\ \times10^{-12}$ F m^{-1}	0.15
permeability of free space	$\mu_0/(4\pi\times10^{-7})$	$1.000\ 000\ 000\ 55(15)$ N A^{-2}	0.15
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	$7.297\ 352\ 5693(11)\times10^{-3} = 1/137.035\ 999\ 084(21)^\dagger$	0.15
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	$2.817\ 940\ 3262(13)\times10^{-15}$ m	0.45
(e^- Compton wavelength)/2π	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	$3.861\ 592\ 6796(12)\times10^{-13}$ m	0.30
Bohr radius ($m_{\text{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	$0.529\ 177\ 210\ 903(80)\times10^{-10}$ m	0.15
wavelength of 1 eV/c particle	$hc/(1\text{ eV})$	$1.239\ 841\ 984\ldots\times10^{-6}$ m	exact*
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	$13.605\ 693\ 122\ 994(26)$ eV	1.9×10^{-3}
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	$0.665\ 245\ 873\ 21(60)$ barn	0.91
Bohr magneton	$\mu_B = e\hbar/2m_e$	$5.788\ 381\ 8060(17)\times10^{-11}$ MeV T^{-1}	0.3
nuclear magneton	$\mu_N = e\hbar/2m_p$	$3.152\ 451\ 258\ 44(96)\times10^{-14}$ MeV T^{-1}	0.31
electron cyclotron freq./field	$\omega^e_{\text{cycl}}/B = e/m_e$	$1.758\ 820\ 010\ 76(53)\times10^{11}$ rad s^{-1} T^{-1}	0.30
proton cyclotron freq./field	$\omega^p_{\text{cycl}}/B = e/m_p$	$9.578\ 833\ 1560(29)\times10^{7}$ rad s^{-1} T^{-1}	0.31
gravitational constant‡	G_N	$6.674\ 30(15)\times10^{-11}$ m^3 kg^{-1} s^{-2}	2.2×10^4
		$= 6.708\ 83(15)\times10^{-39}\ \hbar c\ (\text{GeV}/c^2)^{-2}$	2.2×10^4
standard gravitational accel.	g_N	$9.806\ 65$ m s^{-2}	exact
Avogadro constant	N_A	$6.022\ 140\ 76\times10^{23}$ mol^{-1}	exact
Boltzmann constant	k	$1.380\ 649\times10^{-23}$ J K^{-1}	exact
		$= 8.617\ 333\ 262\ldots\times10^{-5}$ eV K^{-1}	exact*
molar volume, ideal gas at STP	$N_A k$ (273.15 K)/(101 325 Pa)	$22.413\ 969\ 54\ldots\times10^{-3}$ m^3 mol^{-1}	exact*
Wien displacement law constant	$b = \lambda_{\text{max}}T$	$2.897\ 771\ 955\ldots\times10^{-3}$ m K	exact*
Stefan-Boltzmann constant	$\sigma = \pi^2k^4/60\hbar^3c^2$	$5.670\ 374\ 419\ldots\times10^{-8}$ W m^{-2} K^{-4}	exact*
Fermi coupling constant‡‡	$G_F/(\hbar c)^3$	$1.166\ 378\ 7(6)\times10^{-5}$ GeV^{-2}	510
weak-mixing angle	$\sin^2\widehat{\theta}(M_Z)\ (\overline{\text{MS}})$	$0.231\ 22(4)^{\dagger\dagger}$	1.7×10^5
$W^\pm$ boson mass	m_W	$80.379(12)$ GeV/c^2	1.5×10^5
Z^0 boson mass	m_Z	$91.1876(21)$ GeV/c^2	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	$0.1179(10)$	8.5×10^6

$\pi = 3.141\ 592\ 653\ 589\ 793\ 238\ldots$	$e = 2.718\ 281\ 828\ 459\ 045\ 235\ldots$	$\gamma = 0.577\ 215\ 664\ 901\ 532\ 860\ldots$

1 in $\equiv$ 0.0254 m	1 G $\equiv 10^{-4}$ T	1 eV $= 1.602\ 176\ 634\times10^{-19}$ J (exact)	kT at 300 K $= [38.681\ 740(22)]^{-1}$ eV
1 Å $\equiv$ 0.1 nm	1 dyne $\equiv 10^{-5}$ N	$(1\text{ kg})c^2 = 5.609\ 588\ 603\ldots\times10^{35}$ eV (exact*)	0 °C $\equiv$ 273.15 K
1 barn $\equiv 10^{-28}$ m^2	1 erg $\equiv 10^{-7}$ J	1 C $= 2.997\ 924\ 58\times10^9$ esu	1 atmosphere $\equiv$ 760 Torr $\equiv$ 101 325 Pa

$^\sharp$ CODATA recommends that the unit be J/Hz to stress that in $h = E/\nu$ the frequency ν is in cycles/sec (Hz), not radians/sec.
* These are calculated from exact values and are exact to the number of places given (*i.e.* no rounding).
** The molar mass of ^{12}C is 11.999 999 9958(36) g.
† At $Q^2 = 0$. At $Q^2 \approx m_W^2$ the value is $\sim 1/128$.
‡ Absolute laboratory measurements of G_N have been made only on scales of about 1 cm 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 0.23155(4).