1. PHYSICAL CONSTANTS

Table 1.1. Reviewed 1999 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**, (?) (1999) and Rev. Mod. Phys. **72**, (?) (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`

c **speed of light in vacuum**
Value: 299 792 458 m s^{-1}
Uncert. (ppb): exact*

* 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.

h **Planck constant**
Value: $6.626\ 068\ 76(52)\times10^{-34}$ J s
Uncert. (ppb): 78

$\hbar \equiv h/2\pi$ **Planck constant, reduced**
Value: $1.054\ 571\ 596(82)\times10^{-34}$ J s
Uncert. (ppb): 78

Value: $= 6.582\ 118\ 89(26)\times10^{-22}$ MeV s
Uncert. (ppb): 39

e **electron charge magnitude**
Value: $1.602\ 176\ 462(63)\times10^{-19}$ C $= 4.803\ 204\ 20(19)\times10^{-10}$ esu
Uncert. (ppb): 39, 39

$\hbar c$ **conversion constant**
Value: 197.326 960 2(77) MeV fm
Uncert. (ppb): 39

$(\hbar c)^2$ **conversion constant**
Value: 0.389 379 292(30) GeV^2 mbarn
Uncert. (ppb): 78

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m_e **electron mass**
Value: 0.510 998 902(21) MeV/c^2 $= 9.109\ 381\ 88(72)\times10^{-31}$ kg
Uncert. (ppb): 40, 79

m_p **proton mass**
Value: 938.271 998(38) MeV/c^2 $= 1.672\ 621\ 58(13)\times10^{-27}$ kg
Uncert. (ppb): 40, 79

Value: $= 1.007\ 276\ 466\ 88(13)$ u $= 1836.152\ 667\ 5(39)\ m_e$
Uncert. (ppb): 0.13, 2.1

m_d **deuteron mass**
Value: 1875.612 762(75) MeV/c^2
Uncert. (ppb): 40

(mass ^{12}C atom)/12 = (1 g)/(N_A mol) **unified atomic mass unit (u)**
Value: 931.494 013(37) MeV/c^2 = 1.660 538 73(13)$\times 10^{-27}$ kg
Uncert. (ppb): 40, 79

$\epsilon_0 = 1/\mu_0 c^2$ **permittivity of free space**
Value: 8.854 187 817 ... $\times 10^{-12}$ F m^{-1}
Uncert. (ppb): exact

μ_0 **permeability of free space**
Value: $4\pi \times 10^{-7}$ N A^{-2} = 12.566 370 614 ... $\times 10^{-7}$ N A^{-2}
Uncert. (ppb): exact

$\alpha = e^2/4\pi\epsilon_0\hbar c$ **fine-structure constant**
Value: 7.297 352 533(27)$\times 10^{-3}$ = 1/137.035 999 76(50)†
Uncert. (ppb): 3.7,3.7

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

$r_e = e^2/4\pi\epsilon_0 m_e c^2$ **classical electron radius**
Value: 2.817 940 285(31)$\times 10^{-15}$ m
Uncert. (ppb): 11

$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$ **(e^- Compton wavelength)/2π**
Value: 3.861 592 642(28)$\times 10^{-13}$ m
Uncert. (ppb): 7.3

$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$ **Bohr radius ($m_{\rm nucleus} = \infty$)**
Value: 0.529 177 208 3(19)$\times 10^{-10}$ m
Uncert. (ppb): 3.7

hc/e **wavelength of 1 eV/c particle**
Value: 1.239 841 857(49)$\times 10^{-6}$ m
Uncert. (ppb): 39

$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$ **Rydberg energy**
Value: 13.605 691 72(53) eV
Uncert. (ppb): 39

$\sigma_T = 8\pi r_e^2/3$ **Thomson cross section**
Value: 0.665 245 854(15) barn
Uncert. (ppb): 22

$\mu_B = e\hbar/2m_e$ **Bohr magneton**
Value: 5.788 381 749(43)×10^{-11} MeV T^{-1}
Uncert. (ppb): 7.3

$\mu_N = e\hbar/2m_p$ **nuclear magneton**
Value: 3.152 451 238(24)×10^{-14} MeV T^{-1}
Uncert. (ppb): 7.6

$\omega^e_{\rm cycl}/B = e/m_e$ **electron cyclotron freq./field**
Value: 1.758 820 174(71)×10^{11} rad s^{-1} T^{-1}
Uncert. (ppb): 40

$\omega^p_{\rm cycl}/B = e/m_p$ **proton cyclotron freq./field**
Value: 9.578 834 08(38)×10^{7} rad s^{-1} T^{-1}
Uncert. (ppb): 40

G_N **gravitational constant**‡
Value: 6.673(10)×10^{-11} m^3 kg^{-1} s^{-2}
Uncert. (ppb): 1.5×10^6

Value: $= 6.707(10)\times10^{-39}\ \hbar c\ (\mathrm{GeV}/c^2)^{-2}$
Uncert. (ppb): 1.5×10^6

‡ Absolute lab measurements of G_N were performed only on scales of $10^{-1\pm1}$ m.

g_n **standard grav. accel., sea level**
Value: 9.806 65 m s^{-2}
Uncert. (ppb): exact

N_A **Avogadro constant**
Value: 6.022 141 99(47)×10^{23} mol^{-1}
Uncert. (ppb): 79

k **Boltzmann constant**
Value: 1.380 650 3(24)×10^{-23} J K^{-1}
Uncert. (ppb): 1700

Value: $= 8.617\ 342(15)\times10^{-5}$ eV K^{-1}
Uncert. (ppb): 1700

$N_Ak(273.15\ \mathrm{K})/(101\ 325\ \mathrm{Pa})$ **molar volume, ideal gas at STP**
Value: 22.413 996(39)×10^{-3} m^3 mol^{-1}
Uncert. (ppb): 1700

$b = \lambda_{\max} T$ **Wien displacement law constant**
Value: $2.897\,768\,6(51)\times10^{-3}$ m K
Uncert. (ppb): 1700

$\sigma = \pi^2 k^4/60\hbar^3 c^2$ **Stefan-Boltzmann constant**
Value: $5.670\,400(40)\times10^{-8}$ W m^{-2} K^{-4}
Uncert. (ppb): 7000

$G_F/(\hbar c)^3$ **Fermi coupling constant**[**]
Value: $1.166\,39(1)\times10^{-5}$ GeV^{-2}
Uncert. (ppb): 9000

** See discussion in Sec. 10 "Electroweak model and constraints on new physics."

$\sin^2\widehat{\theta}(M_Z)$ ($\overline{\text{MS}}$) **weak mixing angle**
Value: 0.23124(24)
Uncert. (ppb): 1.0×10^6

m_W $\boldsymbol{W^{\pm}}$ **boson mass**
Value: 80.41(10) GeV/c^2
Uncert. (ppb): 1.2×10^6

m_Z $\boldsymbol{Z^0}$ **boson mass**
Value: 91.187(7) GeV/c^2
Uncert. (ppb): 7.7×10^4

$\alpha_s(m_Z)$ **strong coupling constant**
Value: 0.119(2)
Uncert. (ppb): 1.7×10^7

$\pi = 3.141\ 592\ 653\ 589\ 793\ 238$
$e = 2.718\ 281\ 828\ 459\ 045\ 235$
$\gamma = 0.577\ 215\ 664\ 901\ 532\ 861$

$$1 \text{ in} \equiv 0.0254 \text{ m}$$
$$1 \text{ Å} \equiv 10^{-10} \text{ m}$$
$$1 \text{ barn} \equiv 10^{-28} \text{ m}^2$$

$$1 \text{ G} \equiv 10^{-4} \text{ T}$$
$$1 \text{ dyne} \equiv 10^{-5} \text{ N}$$
$$1 \text{ erg} \equiv 10^{-7} \text{ J}$$

$$1 \text{ eV} = 1.602\ \ 176\ \ 462(63) \times 10^{-19} \text{ J}$$
$$1 \text{ eV}/c^2 = 1.782\ \ 661\ \ 731(70) \times 10^{-36} \text{ kg}$$
$$2.997\ \ 924\ \ 58 \times 10^{9} \text{ esu} = 1 \text{ C}$$

$$kT \text{ at } 300 \text{ K} = [38.681\ \ 686(67)]^{-1} \text{ eV}$$
$$0\ \ ^\circ\text{C} \equiv 273.15 \text{ K}$$
$$1 \text{ atmosphere} \equiv 760 \text{ Torr} \equiv 101\ \ 325 \text{ Pa}$$
