1. PHYSICAL CONSTANTS

Table 1.1. Reviewed 1995 by B.N. Taylor, NIST. Based mainly on the "1986 Adjustment of the Fundamental Physical Constants" by E.R. Cohen and B.N. Taylor, Rev. Mod. Phys. **59**, 1121 (1987). 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 million (ppm) 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).

Since the 1986 adjustment, new experiments have yielded improved values for a number of constants, including the Rydberg constant R_∞, the Planck constant h, the fine-structure constant α, and the molar gas constant R, and hence also for constants directly derived from these, such as the Boltzmann constant k and Stefan-Boltzmann constant σ. The new results and their impact on the 1986 recommended values are discussed extensively in "Recommended Values of the Fundamental Physical Constants: A Status Report," B.N. Taylor and E.R. Cohen, J. Res. Natl. Inst. Stand. Technol. **95**, 497 (1990); see also E.R. Cohen and B.N. Taylor, "The Fundamental Physical Constants," Phys. Today, August 1995 Part 2, BG9. In general, the new results give uncertainties for the affected constants that are 5 to 7 times smaller than the 1986 uncertainties, but the changes in the values themselves are smaller than twice the 1986 uncertainties. Because the output values of a least-squares adjustment are correlated, the new results cannot readily be incorporated with the 1986 values. Until the next complete adjustment of the constants, the 1986 CODATA set, given (in part) below, remains the set of choice.

c **speed of light in vacuum**
Value: 299 792 458 m s^{-1}
Uncert. (ppm): 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: $6.626\ 075\ 5(40)\times 10^{-34}$ J s
Uncert. (ppm): 0.60

$\hbar \equiv h/2\pi$ **Planck constant, reduced**
Value: $1.054\ 572\ 66(63)\times 10^{-34}$ J s
Uncert. (ppm): 0.60
Value: $= 6.582\ 122\ 0(20)\times 10^{-22}$ MeV s
Uncert. (ppm): 0.30

e **electron charge magnitude**
Value: $1.602\ 177\ 33(49)\times 10^{-19}$ C $= 4.803\ 206\ 8(15)\times 10^{-10}$ esu
Uncert. (ppm): 0.30, 0.30

$\hbar c$ **conversion constant**
Value: 197.327 053(59) MeV fm
Uncert. (ppm): 0.30

$(\hbar c)^2$ **conversion constant**
Value: 0.389 379 66(23) GeV^2 mbarn
Uncert. (ppm): 0.59

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m_e **electron mass**
Value: 0.510 999 06(15) MeV/c^2 $= 9.109\ 389\ 7(54)\times 10^{-31}$ kg
Uncert. (ppm): 0.30, 0.59

m_p **proton mass**
Value: 938.272 31(28) MeV/c^2 $= 1.672\ 623\ 1(10)\times 10^{-27}$ kg
Uncert. (ppm): 0.30, 0.59
Value: = 1.007 276 470(12) u = 1836.152 701(37) m_e
Uncert. (ppm):0.012, 0.020

m_d **deuteron mass**
Value: 1875.613 39(57) MeV/c^2
Uncert. (ppm): 0.30

(mass ^{12}C atom)/12 = (1 g)/(N_A mol) **unified atomic mass unit (u)**
Value: 931.494 32(28) MeV/c^2 $= 1.660\ 540\ 2(10)\times 10^{-27}$ kg
Uncert. (ppm): 0.30, 0.59

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

$\mu_0 \quad \epsilon_0\mu_0 = 1/c^2$ **permeability of free space**
Value: $4\pi \times 10^{-7}$ N A^{-2} $= 12.566\ 370\ 614 \ldots \times 10^{-7}$ N A^{-2}
Uncert. (ppm): exact

$\alpha = e^2/4\pi\epsilon_0\hbar c$ **fine-structure constant**
Value: $1/137.035\ 989\ 5(61)^\dagger$
Uncert. (ppm): 0.045

† 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: $2.817\ 940\ 92(38) \times 10^{-15}$ m
Uncert. (ppm): 0.13

$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$ **electron Compton wavelength**
Value: $3.861\ 593\ 23(35) \times 10^{-13}$ m
Uncert. (ppm): 0.089

$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$ **Bohr radius ($m_{\text{nucleus}} = \infty$)**
Value: $0.529\ 177\ 249(24) \times 10^{-10}$ m
Uncert. (ppm): 0.045

hc/e **wavelength of 1 eV/c particle**
Value: $1.239\ 842\ 44(37) \times 10^{-6}$ m
Uncert. (ppm): 0.30

$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$ **Rydberg energy**
Value: 13.605 698 1(40) eV
Uncert. (ppm): 0.30

$\sigma_T = 8\pi r_e^2/3$ **Thomson cross section**
Value: 0.665 246 16(18) barn
Uncert. (ppm): 0.27

$\mu_B = e\hbar/2m_e$ **Bohr magneton**
Value: $5.788\ 382\ 63(52) \times 10^{-11}$ MeV T^{-1}
Uncert. (ppm): 0.089

$\mu_N = e\hbar/2m_p$ **nuclear magneton**
Value: $3.152\ 451\ 66(28) \times 10^{-14}$ MeV T^{-1}
Uncert. (ppm): 0.089

$\omega^e_{\rm cycl}/B = e/m_e$ **electron cyclotron freq./field**
Value: $1.758\ 819\ 62(53)\times10^{11}$ rad s^{-1} T^{-1}
Uncert. (ppm): 0.30

$\omega^p_{\rm cycl}/B = e/m_p$ **proton cyclotron freq./field**
Value: $9.578\ 830\ 9(29)\times10^{7}$ rad s^{-1} T^{-1}
Uncert. (ppm): 0.30

G_N **gravitational constant**
Value: $6.672\ 59(85)\times10^{-11}$ m^3 kg^{-1} s^{-2}
Uncert. (ppm): 128
Value: $= 6.707\ 11(86)\times10^{-39}\ \hbar c\ ({\rm GeV}/c^2)^{-2}$
Uncert. (ppm): 128

g **standard grav. accel., sea level**
Value: $9.806\ 65$ m s^{-2}
Uncert. (ppm): exact

N_A **Avogadro constant**
Value: $6.022\ 136\ 7(36)\times10^{23}$ mol^{-1}
Uncert. (ppm): 0.59

k **Boltzmann constant**
Value: $1.380\ 658(12)\times10^{-23}$ J K^{-1}
Uncert. (ppm): 8.5
Value: $= 8.617\ 385(73)\times10^{-5}$ eV K^{-1}
Uncert. (ppm): 8.4

$N_A k(273.15\ {\rm K})/(101\ 325\ {\rm Pa})$ **molar volume, ideal gas at STP**
Value: $22.414\ 10(19)\times10^{-3}$ m^3 mol^{-1}
Uncert. (ppm): 8.4

$b = \lambda_{\rm max} T$ **Wien displacement law constant**
Value: $2.897\ 756(24)\times10^{-3}$ m K
Uncert. (ppm): 8.4

$\sigma = \pi^2 k^4/60\hbar^3 c^2$ **Stefan-Boltzmann constant**
Value: $5.670\ 51(19)\times10^{-8}$ W m^{-2} K^{-4}
Uncert. (ppm): 34

$G_F/(\hbar c)^3$ **Fermi coupling constant**‡
Value: $1.166\ 39(2)\times10^{-5}$ GeV^{-2}
Uncert. (ppm): 20

‡ See discussion in Sec. 10 "Standard Model of electroweak interactions."

$\sin^2\widehat{\theta}(M_Z)$ ($\overline{\text{MS}}$) **weak mixing angle**
Value: 0.2315(4)
Uncert. (ppm): 2200

m_W **$W^{\pm}$ boson mass**
Value: 80.33(15) GeV/c^2
Uncert. (ppm): 1900

m_Z **Z^0 boson mass**
Value: 91.187(7) GeV/c^2
Uncert. (ppm): 77

$\alpha_s(m_Z)$ **strong coupling constant**
Value: 0.118(3)
Uncert. (ppm): 25000

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

$$1\ \text{in} \equiv 0.0254\ \text{m}$$
$$1\ \text{Å} \equiv 0.1\text{nm}$$
$$1\ \text{barn} \equiv 10^{-28}\ \text{m}^2$$

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

$$1\ \text{eV} = 1.602\ \ 177\ \ 33(49) \times 10^{-19}\ \text{J}$$
$$1\ \text{eV}/c^2 = 1.782\ \ 662\ \ 70(54) \times 10^{-36}\ \text{kg}$$
$$2.997\ \ 924\ \ 58 \times 10^{9}\ \text{esu} = 1\ \text{C}$$

$$kT\ \text{at}\ 300\ \text{K} = [38.681\ \ 49(33)]^{-1}\ \text{eV}$$
$$0\ {}^{\circ}\text{C} \equiv 273.15\ \text{K}$$
$$1\ \text{atmosphere} \equiv 760\ \text{torr} \equiv 101\ \ 325\ \text{Pa}$$