

1. PHYSICAL CONSTANTS

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>

2 1. *Physical 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) × 10⁻³⁴ J s

Uncert. (ppb): 78

$\hbar \equiv h/2\pi$ **Planck constant, reduced**

Value: 1.054 571 596(82) × 10⁻³⁴ J s

Uncert. (ppb): 78

Value: = 6.582 118 89(26) × 10⁻²² MeV s

Uncert. (ppb): 39

e **electron charge magnitude**

Value: 1.602 176 462(63) × 10⁻¹⁹ C = 4.803 204 20(19) × 10⁻¹⁰ 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) GeV² mbarn

Uncert. (ppb): 78

m_e **electron mass**

Value: 0.510 998 902(21) MeV/ c^2 = 9.109 381 88(72) × 10⁻³¹ kg

Uncert. (ppb): 40, 79

m_p **proton mass**

Value: 938.271 998(38) MeV/ c^2 = 1.672 621 58(13) × 10⁻²⁷ 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

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

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

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

$\alpha = e^2/4\pi\epsilon_0\hbar c$ **fine-structure constant**
 Value: $7.297\,352\,533(27) \times 10^{-3} = 1/137.035\,999\,76(50)^\dagger$
 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: $2.817\,940\,285(31) \times 10^{-15} \text{ m}$
 Uncert. (ppb): 11

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

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

hc/e **wavelength of 1 eV/c particle**
 Value: $1.239\,841\,857(49) \times 10^{-6} \text{ m}$
 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: $13.605\,691\,72(53) \text{ eV}$
 Uncert. (ppb): 39

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

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

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

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

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

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

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

‡ Absolute lab measurements of G_N have been made only on scales of 1 mm–1 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) $\times 10^{23}$ mol $^{-1}$
Uncert. (ppb): 79

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

Value: = 8.617 342(15) $\times 10^{-5}$ eV K $^{-1}$
Uncert. (ppb): 1700

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

$b = \lambda_{\max} T$ **Wien displacement law constant**
 Value: 2.897 768 6(51) $\times 10^{-3}$ m K
 Uncert. (ppb): 1700

$\sigma = \pi^2 k^4 / 60 \hbar^3 c^2$ **Stefan-Boltzmann constant**
 Value: 5.670 400(40) $\times 10^{-8}$ W m⁻² K⁻⁴
 Uncert. (ppb): 7000

$G_F / (\hbar c)^3$ **Fermi coupling constant****
 Value: 1.166 39(1) $\times 10^{-5}$ GeV⁻²
 Uncert. (ppb): 9000

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

$\sin^2 \hat{\theta}(M_Z) (\overline{\text{MS}})$ **weak-mixing angle**
 Value: 0.23117(16)^{††}
 Uncert. (ppb): 7×10^5

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

m_W **W^\pm boson mass**
 Value: 80.419(56) GeV/ c^2
 Uncert. (ppb): 7×10^5

m_Z **Z^0 boson mass**
 Value: 91.1882(22) GeV/ c^2
 Uncert. (ppb): 2.4×10^4

$\alpha_s(m_Z)$ **strong coupling constant**
 Value: 0.1185(20)
 Uncert. (ppb): 1.7×10^7

6 1. *Physical constants*

$$\pi = 3.141\ 592\ 653\ 589\ 793\ 238$$

$$e = 2.718\ 281\ 828\ 459\ 045\ 235$$

$$\gamma = 0.577\ 215\ 664\ 901\ 532\ 861$$

$$1\ \text{in} \equiv 0.0254\ \text{m}$$

$$1\ \text{\AA} \equiv 0.1\ \text{nm}$$

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

$$1\ \text{G} \equiv 10^{-4}\ \text{T}$$

$$1\ \text{dyne} \equiv 10^{-5}\ \text{N}$$

$$1\ \text{erg} \equiv 10^{-7}\ \text{J}$$

$$1\ \text{eV} = 1.602\ 176\ 462(63) \times 10^{-19}\ \text{J}$$

$$1\ \text{eV}/c^2 = 1.782\ 661\ 731(70) \times 10^{-36}\ \text{kg}$$

$$2.997\ 924\ 58 \times 10^9\ \text{esu} = 1\ \text{C}$$

$$kT\ \text{at}\ 300\ \text{K} = [38.681\ 686(67)]^{-1}\ \text{eV}$$

$$0\ \text{°C} \equiv 273.15\ \text{K}$$

$$1\ \text{atmosphere} \equiv 760\ \text{Torr} \equiv 101\ 325\ \text{Pa}$$
