Table 1.1. Reviewed 1998 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 1997 Part 2, BG7. 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 (expected by the end of 1998), the 1986 CODATA set, given (in part) below, remains the set of choice. The full 1986 set (to be replaced by the new set, when available) may be found at `http://physics.nist.gov/cuu`.

Quantity	Symbol, equation	Value	Uncert. (ppm)
speed of light in vacuum	c	299 792 458 m s^{-1}	exact*
Planck constant	h	6.626 075 5(40)$\times10^{-34}$ J s	0.60
Planck constant, reduced	$\hbar \equiv h/2\pi$	1.054 572 66(63)$\times10^{-34}$ J s	0.60
		= 6.582 122 0(20)$\times10^{-22}$ MeV s	0.30
electron charge magnitude	e	1.602 177 33(49)$\times10^{-19}$ C = 4.803 206 8(15)$\times10^{-10}$ esu	0.30, 0.30
conversion constant	$\hbar c$	197.327 053(59) MeV fm	0.30
conversion constant	$(\hbar c)^2$	0.389 379 66(23) GeV^2 mbarn	0.59
electron mass	m_e	0.510 999 06(15) MeV/c^2 = 9.109 389 7(54)$\times10^{-31}$ kg	0.30, 0.59
proton mass	m_p	938.272 31(28) MeV/c^2 = 1.672 623 1(10)$\times10^{-27}$ kg	0.30, 0.59
		= 1.007 276 470(12) u = 1836.152 701(37) m_e	0.012, 0.020
deuteron mass	m_d	1875.613 39(57) MeV/c^2	0.30
unified atomic mass unit (u)	(mass ^{12}C atom)/12 = (1 g)/(N_A mol)	931.494 32(28) MeV/c^2 = 1.660 540 2(10)$\times10^{-27}$ kg	0.30, 0.59
permittivity of free space	ϵ_0 } $\epsilon_0\mu_0 = 1/c^2$	8.854 187 817 ... $\times10^{-12}$ F m^{-1}	exact
permeability of free space	μ_0	$4\pi\times10^{-7}$ N A^{-2} = 12.566 370 614 ... $\times10^{-7}$ N A^{-2}	exact
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	1/137.035 989 5(61)†	0.045
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 92(38)$\times10^{-15}$ m	0.13
electron Compton wavelength	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	3.861 593 23(35)$\times10^{-13}$ m	0.089
Bohr radius ($m_{\rm nucleus} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	0.529 177 249(24)$\times10^{-10}$ m	0.045
wavelength of 1 eV/c particle	hc/e	1.239 842 44(37)$\times10^{-6}$ m	0.30
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	13.605 698 1(40) eV	0.30
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0.665 246 16(18) barn	0.27
Bohr magneton	$\mu_B = e\hbar/2m_e$	5.788 382 63(52)$\times10^{-11}$ MeV T^{-1}	0.089
nuclear magneton	$\mu_N = e\hbar/2m_p$	3.152 451 66(28)$\times10^{-14}$ MeV T^{-1}	0.089
electron cyclotron freq./field	$\omega^e_{\rm cycl}/B = e/m_e$	1.758 819 62(53)$\times10^{11}$ rad s^{-1} T^{-1}	0.30
proton cyclotron freq./field	$\omega^p_{\rm cycl}/B = e/m_p$	9.578 830 9(29)$\times10^{7}$ rad s^{-1} T^{-1}	0.30
gravitational constant‡	G_N	6.672 59(85)$\times10^{-11}$ m^3 kg^{-1} s^{-2}	128
		= 6.707 11(86)$\times10^{-39}$ $\hbar c$ (GeV/c^2)$^{-2}$	128
standard grav. accel., sea level	g	9.806 65 m s^{-2}	exact
Avogadro constant	N_A	6.022 136 7(36)$\times10^{23}$ mol^{-1}	0.59
Boltzmann constant	k	1.380 658(12)$\times10^{-23}$ J K^{-1}	8.5
		= 8.617 385(73)$\times10^{-5}$ eV K^{-1}	8.4
molar volume, ideal gas at STP	$N_A k$(273.15 K)/(101 325 Pa)	22.414 10(19)$\times10^{-3}$ m^3 mol^{-1}	8.4
Wien displacement law constant	$b = \lambda_{\rm max}T$	2.897 756(24)$\times10^{-3}$ m K	8.4
Stefan-Boltzmann constant	$\sigma = \pi^2k^4/60\hbar^3c^2$	5.670 51(19)$\times10^{-8}$ W m^{-2} K^{-4}	34
Fermi coupling constant**	$G_F/(\hbar c)^3$	1.166 39(1)$\times10^{-5}$ GeV^{-2}	9
weak mixing angle	$\sin^2\hat\theta(M_Z)$ ($\overline{\rm MS}$)	0.23124(24)	1000
$W^\pm$ boson mass	m_W	80.41(10) GeV/c^2	1200
Z^0 boson mass	m_Z	91.187(7) GeV/c^2	77
strong coupling constant	$\alpha_s(m_Z)$	0.119(2)	17000

π = 3.141 592 653 589 793 238	e = 2.718 281 828 459 045 235	γ = 0.577 215 664 901 532 861

1 in ≡ 0.0254 m	1 G ≡ 10^{-4} T	1 eV = 1.602 177 33(49) × 10^{-19} J	kT at 300 K = [38.681 49(33)]$^{-1}$ eV
1 Å ≡ 10^{-10} m	1 dyne ≡ 10^{-5} N	1 eV/c^2 = 1.782 662 70(54) × 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 performed only on scales of $10^{-1\pm1}$ m.

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

7. ELECTROMAGNETIC RELATIONS

Quantity	Gaussian CGS	SI
Conversion factors: Charge: Potential: Magnetic field:	 $2.997\,924\,58 \times 10^9$ esu (1/299.792 458) statvolt (ergs/esu) 10^4 gauss $= 10^4$ dyne/esu	 $= 1$ C $= 1$ A s $= 1$ V $= 1$ J C^{-1} $= 1$ T $= 1$ N A^{-1}m^{-1}
Lorentz force:	$\mathbf{F} = q\,(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B})$	$\mathbf{F} = q\,(\mathbf{E} + \mathbf{v} \times \mathbf{B})$
Maxwell equations:	$\boldsymbol{\nabla} \cdot \mathbf{D} = 4\pi\rho$ $\boldsymbol{\nabla} \times \mathbf{H} - \frac{1}{c}\frac{\partial \mathbf{D}}{\partial t} = \frac{4\pi}{c}\mathbf{J}$ $\boldsymbol{\nabla} \cdot \mathbf{B} = 0$ $\boldsymbol{\nabla} \times \mathbf{E} + \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} = 0$	$\boldsymbol{\nabla} \cdot \mathbf{D} = \rho$ $\boldsymbol{\nabla} \times \mathbf{H} - \frac{\partial \mathbf{D}}{\partial t} = \mathbf{J}$ $\boldsymbol{\nabla} \cdot \mathbf{B} = 0$ $\boldsymbol{\nabla} \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} = 0$
Constitutive relations:	$\mathbf{D} = \mathbf{E} + 4\pi\mathbf{P}, \quad \mathbf{H} = \mathbf{B} - 4\pi\mathbf{M}$	$\mathbf{D} = \epsilon_0\mathbf{E} + \mathbf{P}, \quad \mathbf{H} = \mathbf{B}/\mu_0 - \mathbf{M}$
Linear media: Permitivity of free space: Permeability of free space:	$\mathbf{D} = \epsilon\mathbf{E}, \quad \mathbf{H} = \mathbf{B}/\mu$ 1 1	$\mathbf{D} = \epsilon\mathbf{E}, \quad \mathbf{H} = \mathbf{B}/\mu$ $\epsilon_0 = 8.854\,187\ldots \times 10^{-12}$ F m^{-1} $\mu_0 = 4\pi \times 10^{-7}$ N A^{-2}
Fields from potentials:	$\mathbf{E} = -\boldsymbol{\nabla} V - \frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}$ $\mathbf{B} = \boldsymbol{\nabla} \times \mathbf{A}$	$\mathbf{E} = -\boldsymbol{\nabla} V - \frac{\partial \mathbf{A}}{\partial t}$ $\mathbf{B} = \boldsymbol{\nabla} \times \mathbf{A}$
Static potentials: (coulomb gauge)	$V = \sum_{\text{charges}} \frac{q_i}{r_i} = \int \frac{\rho\,(\mathbf{r}')}{\lvert\mathbf{r} - \mathbf{r}'\rvert}\, d^3x'$ $\mathbf{A} = \frac{1}{c}\oint \frac{I\,\mathbf{d}\boldsymbol{\ell}}{\lvert\mathbf{r} - \mathbf{r}'\rvert} = \frac{1}{c}\int \frac{\mathbf{J}(\mathbf{r}')}{\lvert\mathbf{r} - \mathbf{r}'\rvert}\, d^3x'$	$V = \frac{1}{4\pi\epsilon_0} \sum_{\text{charges}} \frac{q_i}{r_i} = \frac{1}{4\pi\epsilon_0}\int \frac{\rho\,(\mathbf{r}')}{\lvert\mathbf{r} - \mathbf{r}'\rvert}\, d^3x'$ $\mathbf{A} = \frac{\mu_0}{4\pi}\oint \frac{I\,\mathbf{d}\boldsymbol{\ell}}{\lvert\mathbf{r} - \mathbf{r}'\rvert} = \frac{\mu_0}{4\pi}\int \frac{\mathbf{J}(\mathbf{r}')}{\lvert\mathbf{r} - \mathbf{r}'\rvert}\, d^3x'$
Relativistic transformations: ($\mathbf{v}$ is the velocity of the primed frame as seen in the unprimed frame)	$\mathbf{E}'_{\parallel} = \mathbf{E}_{\parallel}$ $\mathbf{E}'_{\perp} = \gamma(\mathbf{E}_{\perp} + \frac{1}{c}\mathbf{v} \times \mathbf{B})$ $\mathbf{B}'_{\parallel} = \mathbf{B}_{\parallel}$ $\mathbf{B}'_{\perp} = \gamma(\mathbf{B}_{\perp} - \frac{1}{c}\mathbf{v} \times \mathbf{E})$	$\mathbf{E}'_{\parallel} = \mathbf{E}_{\parallel}$ $\mathbf{E}'_{\perp} = \gamma(\mathbf{E}_{\perp} + \mathbf{v} \times \mathbf{B})$ $\mathbf{B}'_{\parallel} = \mathbf{B}_{\parallel}$ $\mathbf{B}'_{\perp} = \gamma(\mathbf{B}_{\perp} - \frac{1}{c^2}\mathbf{v} \times \mathbf{E})$

$$\frac{1}{4\pi\epsilon_0} = c^2 \times 10^{-7}\ \text{N A}^{-2} = 8.987\,55\ldots \times 10^9\ \text{m F}^{-1}\ ; \qquad \frac{\mu_0}{4\pi} = 10^{-7}\ \text{N A}^{-2}\ ; \qquad c = \frac{1}{\sqrt{\mu_0\epsilon_0}} = 2.997\,924\ 58 \times 10^8\ \text{m s}^{-1}$$

Appendix 3
Physical constants

3.1 Frequently used nuclear constants

The frequently used constants are given below in familiar units. Only approximate values are given, see Table A3.1 for values to current known precision

Symbol	*Constant*	*Value*
$1/\alpha = 4\pi\varepsilon_0\hbar c/e^2$	Reciprocal of fine structure constant	137.0
c	Speed of light in vacuum	2.998×10^{10} cm s^{-1}
h	Planck constant	6.626×10^{-27} erg s
$\hbar = h/2\pi$	Reduced Planck constant	6.582×10^{-22} MeV s
$\hbar c$		197.3 MeV fm
$k = R/N_A$	Boltzmann constant	8.617×10^{-11} MeV K^{-1}
$r_e = e^2/4\pi\varepsilon_0 m_e c^2$	Classical e$^-$ radius	2.818 fm
$\lambda_{C,e} = \hbar/m_e c$	Compton wavelength of e$^-$	386.2 fm
$\lambda_{C,p} = \hbar/m_p c$	Compton wavelength of p	0.210 fm
$\lambda_{C,\pi} = \hbar/m_\pi c$	Compton wavelength of π	1.414 fm
u	Atomic mass unit	931.5 MeV/c^2
m_e	Electron mass	0.511 MeV/c^2
m_n	Neutron mass	939.6 MeV/c^2
m_p	Proton mass	938.3 MeV/c^2
m_d	Deuteron mass	1875.6 MeV/c^2
$m_{\pi^\pm}$	$\pi^\pm$ mass	139.6 MeV/c^2
m_{π^0}	π^0 mass	135.0 MeV/c^2
m_W	W$^\pm$ boson mass	80.2 GeV/c^2
m_Z	Z^0 boson mass	91.2 GeV/c^2
$\mu_N = \hbar e/2m_p c$	Nuclear magneton	3.152×10^{-18} MeV Gauss^{-1}
μ_p	Proton magnetic moment	2.793 μ_N
μ_n	Neutron magnetic moment	-1.913 μ_N

1 fm $= 10^{-13}$ cm
1 barn $= 10^{-24}$ cm^2
1 joule $= 10^7$ erg
1 newton $= 10^5$ dyne
1 Å $= 10^{-8}$ cm
1 eV/c $= 1.783 \times 10^{-33}$ g
1 coulomb $= 2.998 \times 10^9$ esu
1 tesla $= 10^4$ gauss
$\pi = 3.1416$