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The 1986 CODATA Recommended Values of the Fundamental Physical Constants

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Presented here are the values of the basic constants and conversion factors of physics and chemistry resulting from the 1986 least-squares adjustment of the fundamental physical constants as published by the CODATA (Committee on Data for Science and Technology) Task Group on Fundamental Constants and recommended for international use by CODATA. The 1986 CODATA set of values replaces its predecessor published by the Task Group and recommended for international use by CODATA in 1973.

Key words: fundamental physical constants; conversion factors; CODATA; Task Group on Fundamental Constants; least-squares adjustments; recommended values.

CODATA (Committee on Data for Science and Technology) was established in 1966 as an interdisciplinary committee of the International Council of Scientific Unions. It seeks to improve the compilation, critical evaluation, storage, and retrieval of data of importance to science and technology. Dr. David R. Lide, Chief of the Office of Standard Reference Data of the National Institute of Standards and Technology (formerly the National Bureau of Standards), is the current President of CODATA.

In late 1986[1] and also in 1987,[2] CODATA published a report of the CODATA Task Group on Fundamental Constants prepared by the authors under the auspices and guidance of the Task Group. The report summarizes the 1986 least-squares adjustment of the fundamental physical constants and gives a set of self-consistent values for the basic constants and conversion factors of physics and chemistry derived from that adjustment. Recommended for international use by CODATA, this 1986 set of values is reprinted here for the convenience of the many readers of the *Journal of Physical and Chemical Reference Data* and to assist in its dissemination throughout the scientific and technological communities. The 1986 CODATA set replaces its immediate predecessor, that recommended for international use by CODATA in 1973. This set was based on the 1973 least-squares adjustment of the fundamental physical constants which was also carried out by the authors under the auspices and guidance of the Task Group.[3,4] The 1986 adjustment represents a major advance over its 1973 counterpart; the uncertainties of the recommended values have been reduced by roughly an order of magnitude due to the enormous advances made throughout the precision measurement-fundamental constants field during the 13 years that elapsed between the two adjustments.

The 1986 recommended values of the fundamental physical constants are given in five tables. Table 1 is an abbreviated list containing the quantities which should be of greatest interest to most users. Table 2 is a much more complete compilation. Table 3 is a list of related "maintained" units and "standard" values, while Table 4 contains a number of scientifically, technologically, and metrologically useful energy conversion factors. Finally, Table 5 is an extended variance matrix containing the variances, covariances, and correlation coefficients of the variables of the adjustment and of a number of other constants included for convenience. Such a matrix is necessary, of course, because the variables in a least-squares adjustment are statistically correlated. Thus, with the exception of quantities which depend only on auxiliary constants, the uncertainty associated with a quantity calculated from these variables can be found only with the use of the full variance matrix. (Auxiliary constants are either defined quantities with no uncertainty, or quantities such as the Rydberg constant R_∞ with assigned uncertainties sufficiently small that their values are not subject to adjustment. In the 1986 least-squares adjustment, the uncertainty of each auxiliary constant was no greater than 0.02 parts-per-million or ppm.)

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In Table 5, K_V is the numerical value of the laboratory unit of voltage $V_{76\text{-BI}}$ maintained at the Bureau International des Poids et Mesures (BIPM): $V_{76\text{-BI}} = K_V\,V$. $V_{76\text{-BI}}$ is based on the Josephson effect using a value of the Josephson frequency to voltage quotient $2e/h$ adopted in 1972 by the Comité Consultatif d'Électricité of the Comité International des Poids et Mesures, namely, $E = 483\,594$ GHz/V exactly; thus $2e/h = E/K_V$. K_Ω is the numerical value of the BIPM as maintained ohm as it existed on 1 January 1985, Ω_{BI85}, based on the mean resistance of a particular group of wire-wound resistors: $\Omega_{\text{BI85}} = K_\Omega\,\Omega$.

To use Table 5, note that the covariance between two quantities Q_k and Q_s which are functions of a common set of variables x_i ($i = 1,\ldots,N$) is given by

$$v_{ks} = \sum_{i,j=1}^{N} \frac{\partial Q_k}{\partial x_i}\frac{\partial Q_s}{\partial x_j} v_{ij}, \qquad (1)$$

where v_{ij} is the covariance of x_i and x_j. In this general form, the units of v_{ij} are the product of the units of x_i and x_j and the units of v_{ks} are the product of the units of Q_k and Q_s. For most cases involving the fundamental constants, the variables x_i may be taken to be the fractional change in the physical quantity from some fiducial value, and the quantities Q can be expressed as powers of physical constants Z_j according to

$$Q_k = q_k \prod_{j=1}^{N} Z_j^{Y_{kj}} = q_k \prod_{j=1}^{N} Z_{0j}^{Y_{kj}}(1 + x_j)^{Y_{kj}}, \qquad (2)$$

where q_k is a constant. If the variances and covariances are then expressed in relative units Eq. (1) becomes

$$v_{ks} = \sum_{i,j=1}^{N} Y_{ki} Y_{sj} v_{ij}, \qquad (3)$$

where the v_{ij} are to be expressed, for example, in (parts in $10^9)^2$. Equation (3) is the basis for the expansion of the variance matrix to include e, h, m_e, N_A, and F. In terms of correlation coefficients r_{ij} defined by $v_{ij} = r_{ij}(v_{ii}v_{jj})^{1/2} = r_{ij}\epsilon_i\epsilon_j$, where ϵ_i is the standard deviation ($\epsilon_i^2 = v_{ii}$), we may write

$$\epsilon_k^2 = \sum_{i=1}^{N} Y_{ki}^2\epsilon_i^2 + 2\sum_{j<i}^{N} Y_{ki}Y_{kj}r_{ij}\epsilon_i\epsilon_j. \qquad (4)$$

As an example of the use of Table 5, consider the calculation of the uncertainty of the Bohr magneton $\mu_B = eh/4\pi m_e$. In terms of the variables of the 1986 adjustment this quantity is given by

$$\mu_B = [2\pi\mu_0 R_\infty E]^{-1}\cdot(\alpha^{-1})^{-3}K_V, \qquad (5)$$

where the quantities in the brackets to the left of the centered dot are taken to be exact. Using Eq. (3) with $i = 1$ corresponding to α^{-1} and $i = 2$ corresponding to K_V, and dropping the subscript k because there is only a single quantity, $Q = \mu_B$, gives

$$\epsilon^2 = Y_1^2 v_{11} + 2Y_1Y_2v_{12} + Y_2^2 v_{22}, \qquad (6)$$

where $Y_1 = -3$ and $Y_2 = 1$. Thus taking the appropriate entries from Table 5 leads to

$$\epsilon^2 = [9(1997) - 6(-1062) + 87\,988](10^{-9})^2 \qquad (7)$$

or $\epsilon = 0.335$ ppm. Alternatively, one may evaluate eh/m_e directly from Table 5, using $i = 5$ corresponding to e, $i = 6$ to h, and $i = 7$ to m_e with $Y_5 = 1$, $Y_6 = 1$, and $Y_7 = -1$. Then

$$\epsilon^2 = Y_5^2 v_{55} + 2Y_5Y_6v_{56} + 2Y_5Y_7v_{57} + Y_6^2 v_{66} + 2Y_6Y_7v_{67} + Y_7^2 v_{77} \qquad (8a)$$

$$= [92\,109 + 2(181\,159) - 2(175\,042) + 358\,197 - 2(349\,956) + 349\,702](10^{-9})^2 \qquad (8b)$$

which also yields $\epsilon = 0.335$ ppm.

TABLE 1. Summary of the 1986 recommended values of the fundamental physical constants. An abbreviated list of the fundamental constants of physics and chemistry based on a least-squares adjustment with 17 degrees of freedom. The digits in parentheses are the one-standard-deviation uncertainty in the last digits of the given value. Since the uncertainties of many of these entries are correlated, the full variance matrix must be used in evaluating the uncertainties of quantities computed for them.

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
speed of light in vacuum	c	299 792 458	$\mathrm{m\,s^{-1}}$	(exact)
permeability of vacuum	μ_0	$4\pi \times 10^{-7}$	$\mathrm{N\,A^{-2}}$	
		= 12.566 370 614...	10^{-7} $\mathrm{N\,A^{-2}}$	(exact)
permittivity of vacuum, $1/\mu_0 c^2$	ε_0	8.854 187 817...	10^{-12} $\mathrm{F\,m^{-1}}$	(exact)
Newtonian constant of gravitation	G	6.672 59(85)	10^{-11} $\mathrm{m^3\,kg^{-1}\,s^{-2}}$	128
Planck constant	h	6.626 075 5(40)	10^{-34} $\mathrm{J\,s}$	0.60
$h/2\pi$	$\hbar$	1.054 572 66(63)	10^{-34} $\mathrm{J\,s}$	0.60
elementary charge	e	1.602 177 33(49)	10^{-19} C	0.30
magnetic flux quantum, $h/2e$	Φ_0	2.067 834 61(61)	10^{-15} Wb	0.30
electron mass	m_e	9.109 389 7(54)	10^{-31} kg	0.59
proton mass	m_p	1.672 623 1(10)	10^{-27} kg	0.59
proton-electron mass ratio	m_p/m_e	1 836.152 701(37)		0.020
fine-structure constant, $\mu_0 ce^2/2h$	α	7.297 353 08(33)	10^{-3}	0.045
inverse fine-structure constant	α^{-1}	137.035 989 5(61)		0.045
Rydberg constant, $m_e c\alpha^2/2h$	R_∞	10 973 731.534(13)	$\mathrm{m^{-1}}$	0.0012
Avogadro constant	N_A, L	6.022 136 7(36)	10^{23} $\mathrm{mol^{-1}}$	0.59
Faraday constant, $N_A e$	F	96 485.309(29)	$\mathrm{C\,mol^{-1}}$	0.30
molar gas constant	R	8.314 510(70)	$\mathrm{J\,mol^{-1}\,K^{-1}}$	8.4
Boltzmann constant, R/N_A	k	1.380 658(12)	10^{-23} $\mathrm{J\,K^{-1}}$	8.5
Stefan-Boltzmann constant, $(\pi^2/60)k^4/\hbar^3c^2$	σ	5.670 51(19)	10^{-8} $\mathrm{W\,m^{-2}\,K^{-4}}$	34
		Non-SI units used with SI		
electron volt, $(e/\mathrm{C})\mathrm{J} = \{e\}\mathrm{J}$	eV	1.602 177 33(49)	10^{-19} J	0.30
(unified) atomic mass unit, $1\ \mathrm{u} = m_u = \frac{1}{12}m(^{12}\mathrm{C})$	u	1.660 540 2(10)	10^{-27} kg	0.59

TABLE 2. 1986 recommended values of the fundamental physical constants. This list of the fundamental constants of physics and chemistry is based on a least-squares adjustment with 17 degrees of freedom. The digits in parentheses are the one-standard-deviation uncertainty in the last digits of the given value. Since the uncertainties of many of these entries are correlated, the full variance matrix must be used in evaluating the uncertainties of quantities computed from them.

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
GENERAL CONSTANTS				
Universal constants				
speed of light in vacuum	c	299 792 458	m s^{-1}	(exact)
permeability of vacuum	μ_0	$4\pi \times 10^{-7}$	N A^{-2}	
		$=$12.566 370 614...	10^{-7} N A^{-2}	(exact)
permittivity of vacuum, $1/\mu_0 c^2$	ε_0	8.854 187 817...	10^{-12} F m^{-1}	(exact)
Newtonian constant of gravitation	G	6.672 59(85)	10^{-11} m^3 kg^{-1} s^{-2}	128
Planck constant	h	6.626 075 5(40)	10^{-34} J s	0.60
in electron volts, $h/\{e\}$		4.135 669 2(12)	10^{-15} eV s	0.30
$h/2\pi$	$\hbar$	1.054 572 66(63)	10^{-34} J s	0.60
in electron volts, $\hbar/\{e\}$		6.582 122 0(20)	10^{-16} eV s	0.30
Planck mass, $(\hbar c/G)^{1/2}$	m_{P}	2.176 71(14)	10^{-8} kg	64
Planck length, $\hbar/m_{\mathrm{P}}c = (\hbar G/c^3)^{1/2}$	l_{P}	1.616 05(10)	10^{-35} m	64
Planck time, $l_{\mathrm{P}}/c = (\hbar G/c^5)^{1/2}$	t_{P}	5.390 56(34)	10^{-44} s	64
Electromagnetic constants				
elementary charge	e	1.602 177 33(49)	10^{-19} C	0.30
	e/h	2.417 988 36(72)	10^{14} A J^{-1}	0.30
magnetic flux quantum, $h/2e$	Φ_0	2.067 834 61(61)	10^{-15} Wb	0.30
Josephson frequency-voltage quotient	$2e/h$	4.835 976 7(14)	10^{14} Hz V^{-1}	0.30
quantized Hall conductance	e^2/h	3.874 046 14(17)	10^{-5} S	0.045
quantized Hall resistance, $h/e^2 = \mu_0 c/2\alpha$	R_{H}	25 812.805 6(12)	Ω	0.045
Bohr magneton, $e\hbar/2m_{\mathrm{e}}$	μ_{B}	9.274 015 4(31)	10^{-24} J T^{-1}	0.34
in electron volts, $\mu_{\mathrm{B}}/\{e\}$		5.788 382 63(52)	10^{-5} eV T^{-1}	0.089
in hertz, μ_{B}/h		1.399 624 18(42)	10^{10} Hz T^{-1}	0.30
in wavenumbers, μ_{B}/hc		46.686 437(14)	m^{-1} T^{-1}	0.30
in kelvins, μ_{B}/k		0.671 709 9(57)	K T^{-1}	8.5
nuclear magneton, $e\hbar/2m_{\mathrm{p}}$	μ_{N}	5.050 786 6(17)	10^{-27} J T^{-1}	0.34
in electron volts, $\mu_{\mathrm{N}}/\{e\}$		3.152 451 66(28)	10^{-8} eV T^{-1}	0.089
in hertz, μ_{N}/h		7.622 591 4(23)	MHz T^{-1}	0.30
in wavenumbers, μ_{N}/hc		2.542 622 81(77)	10^{-2} m^{-1} T^{-1}	0.30
in kelvins, μ_{N}/k		3.658 246(31)	10^{-4} K T^{-1}	8.5
ATOMIC CONSTANTS				
fine-structure constant, $\mu_0 c e^2/2h$	α	7.297 353 08(33)	10^{-3}	0.045
inverse fine-structure constant	α^{-1}	137.035 989 5(61)		0.045
Rydberg constant, $m_{\mathrm{e}} c \alpha^2/2h$	R_∞	10 973 731.534(13)	m^{-1}	0.0012
in hertz, $R_\infty c$		3.289 841 949 9(39)	10^{15} Hz	0.0012
in joules, $R_\infty hc$		2.179 874 1(13)	10^{-18} J	0.60
in eV, $R_\infty hc/\{e\}$		13.605 698 1(40)	eV	0.30
Bohr radius, $\alpha/4\pi R_\infty$	a_0	0.529 177 249(24)	10^{-10} m	0.045
Hartree energy, $e^2/4\pi\varepsilon_0 a_0 = 2R_\infty hc$	E_{h}	4.359 748 2(26)	10^{-18} J	0.60
in eV, $E_{\mathrm{h}}/\{e\}$		27.211 396 1(81)	eV	0.30
quantum of circulation	$h/2m_{\mathrm{e}}$	3.636 948 07(33)	10^{-4} m^2 s^{-1}	0.089
	h/m_{e}	7.273 896 14(65)	10^{-4} m^2 s^{-1}	0.089
Electron				
electron mass	m_{e}	9.109 389 7(54)	10^{-31} kg	0.59
		5.485 799 03(13)	10^{-4} u	0.023
in electron volts, $m_{\mathrm{e}} c^2/\{e\}$		0.510 999 06(15)	MeV	0.30
electron-muon mass ratio	m_{e}/m_μ	4.836 332 18(71)	10^{-3}	0.15
electron-proton mass ratio	$m_{\mathrm{e}}/m_{\mathrm{p}}$	5.446 170 13(11)	10^{-4}	0.020
electron-deuteron mass ratio	$m_{\mathrm{e}}/m_{\mathrm{d}}$	2.724 437 07(6)	10^{-4}	0.020
electron–α-particle mass ratio	m_{e}/m_α	1.370 933 54(3)	10^{-4}	0.021
electron specific charge	$-e/m_{\mathrm{e}}$	$-$1.758 819 62(53)	10^{11} C kg^{-1}	0.30

TABLE 2. (*Continued*).

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
Electron *(Continued)*				
electron molar mass	$M(\mathrm{e}), M_e$	5.485 799 03(13)	10^{-7} kg/mol	0.023
Compton wavelength, h/m_ec	λ_C	2.426 310 58(22)	10^{-12} m	0.089
$\lambda_C/2\pi = \alpha a_0 = \alpha^2/4\pi R_\infty$	$\lambdabar_C$	3.861 593 23(35)	10^{-13} m	0.089
classical electron radius, $\alpha^2 a_0$	r_e	2.817 940 92(38)	10^{-15} m	0.13
Thomson cross section, $(8\pi/3)r_e^2$	σ_e	0.665 246 16(18)	10^{-28} m^2	0.27
electron magnetic moment	μ_e	928.477 01(31)	10^{-26} $\mathrm{J\,T^{-1}}$	0.34
in Bohr magnetons	μ_e/μ_B	1.001 159 652 193(10)		1×10^{-5}
in nuclear magnetons	μ_e/μ_N	1 838.282 000(37)		0.020
electron magnetic moment anomaly, $\mu_e/\mu_B - 1$	a_e	1.159 652 193(10)	10^{-3}	0.0086
electron g factor, $2(1+a_e)$	g_e	2.002 319 304 386(20)		1×10^{-5}
electron-muon magnetic moment ratio	μ_e/μ_μ	206.766 967(30)		0.15
electron-proton magnetic moment ratio	μ_e/μ_p	658.210 688 1(66)		0.010
Muon				
muon mass	m_μ	1.883 532 7(11)	10^{-28} kg	0.61
		0.113 428 913(17)	u	0.15
in electron volts, $m_\mu c^2/\{e\}$		105.658 389(34)	MeV	0.32
muon-electron mass ratio	m_μ/m_e	206.768 262(30)		0.15
muon molar mass	$M(\mu), M_\mu$	1.134 289 13(17)	10^{-4} kg/mol	0.15
muon magnetic moment	μ_μ	4.490 451 4(15)	10^{-26} $\mathrm{J\,T^{-1}}$	0.33
in Bohr magnetons,	μ_μ/μ_B	4.841 970 97(71)	10^{-3}	0.15
in nuclear magnetons,	μ_μ/μ_N	8.890 598 1(13)		0.15
muon magnetic moment anomaly, $[\mu_\mu/(e\hbar/2m_\mu)]-1$	a_μ	1.165 923 0(84)	10^{-3}	7.2
muon g factor, $2(1+a_\mu)$	g_μ	2.002 331 846(17)		0.0084
muon-proton magnetic moment ratio	μ_μ/μ_p	3.183 345 47(47)		0.15
Proton				
proton mass	m_p	1.672 623 1(10)	10^{-27} kg	0.59
		1.007 276 470(12)	u	0.012
in electron volts, $m_pc^2/\{e\}$		938.272 31(28)	MeV	0.30
proton-electron mass ratio	m_p/m_e	1 836.152 701(37)		0.020
proton-muon mass ratio	m_p/m_μ	8.880 244 4(13)		0.15
proton specific charge	e/m_p	9.578 830 9(29)	10^7 $\mathrm{C\,kg^{-1}}$	0.30
proton molar mass	$M(\mathrm{p}), M_p$	1.007 276 470(12)	10^{-3} kg/mol	0.012
proton Compton wavelength, h/m_pc	$\lambda_{C,p}$	1.321 410 02(12)	10^{-15} m	0.089
$\lambda_{C,p}/2\pi$	$\lambdabar_{C,p}$	2.103 089 37(19)	10^{-16} m	0.089
proton magnetic moment	μ_p	1.410 607 61(47)	10^{-26} $\mathrm{J\,T^{-1}}$	0.34
in Bohr magnetons	μ_p/μ_B	1.521 032 202(15)	10^{-3}	0.010
in nuclear magnetons	μ_p/μ_N	2.792 847 386(63)		0.023
diamagnetic shielding correction for protons in pure water, spherical sample, 25 °C, $1-\mu_p'/\mu_p$	σ_{H_2O}	25.689(15)	10^{-6}	
shielded proton moment (H_2O, sph., 25 °C)	μ_p'	1.410 571 38(47)	10^{-26} $\mathrm{J\,T^{-1}}$	0.34
in Bohr magnetons	μ_p'/μ_B	1.520 993 129(17)	10^{-3}	0.011
in nuclear magnetons	μ_p'/μ_N	2.792 775 642(64)		0.023
proton gyromagnetic ratio	γ_p	26 752.212 8(81)	10^4 $\mathrm{s^{-1}\,T^{-1}}$	0.30
	$\gamma_p/2\pi$	42.577 469(13)	$\mathrm{MHz\,T^{-1}}$	0.30
uncorrected (H_2O, sph., 25 °C)	γ_p'	26 751.525 5(81)	10^4 $\mathrm{s^{-1}\,T^{-1}}$	0.30
	$\gamma_p'/2\pi$	42.576 375(13)	$\mathrm{MHz\,T^{-1}}$	0.30

TABLE 2. (*Continued*).

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
Neutron				
neutron mass	m_n	1.674 928 6(10)	10^{-27} kg	0.59
		1.008 664 904(14)	u	0.014
in electron volts, $m_n c^2/\{e\}$		939.565 63(28)	MeV	0.30
neutron-electron mass ratio	m_n/m_e	1 838.683 662(40)		0.022
neutron-proton mass ratio	m_n/m_p	1.001 378 404(9)		0.009
neutron molar mass	$M(\mathrm{n}), M_n$	1.008 664 904(14)	10^{-3} kg/mol	0.014
neutron Compton wavelength, $h/m_n c$	$\lambda_{C,n}$	1.319 591 10(12)	10^{-15} m	0.089
$\lambda_{C,n}/2\pi$	$\bar{\lambda}_{C,n}$	2.100 194 45(19)	10^{-16} m	0.089
neutron magnetic moment[a]	μ_n	0.966 237 07(40)	10^{-26} J T^{-1}	0.41
in Bohr magnetons	μ_n/μ_B	1.041 875 63(25)	10^{-3}	0.24
in nuclear magnetons	μ_n/μ_N	1.913 042 75(45)		0.24
neutron-electron magnetic moment ratio	μ_n/μ_e	1.040 668 82(25)	10^{-3}	0.24
neutron-proton magnetic moment ratio	μ_n/μ_p	0.684 979 34(16)		0.24
Deuteron				
deuteron mass	m_d	3.343 586 0(20)	10^{-27} kg	0.59
		2.013 553 214(24)	u	0.012
in electron volts, $m_d c^2/\{e\}$		1 875.613 39(57)	MeV	0.30
deuteron-electron mass ratio	m_d/m_e	3 670.483 014(75)		0.020
deuteron-proton mass ratio	m_d/m_p	1.999 007 496(6)		0.003
deuteron molar mass	$M(\mathrm{d}), M_d$	2.013 553 214(24)	10^{-3} kg/mol	0.012
deuteron magnetic moment[a]	μ_d	0.433 073 75(15)	10^{-26} J T^{-1}	0.34
in Bohr magnetons,	μ_d/μ_B	0.466 975 447 9(91)	10^{-3}	0.019
in nuclear magnetons,	μ_d/μ_N	0.857 438 230(24)		0.028
deuteron-electron magnetic moment ratio	μ_d/μ_e	0.466 434 546 0(91)	10^{-3}	0.019
deuteron-proton magnetic moment ratio	μ_d/μ_p	0.307 012 203 5(51)		0.017
PHYSICO-CHEMICAL CONSTANTS				
Avogadro constant	N_A, L	6.022 136 7(36)	10^{23} mol^{-1}	0.59
atomic mass constant $m_u = \frac{1}{12} m(^{12}\mathrm{C})$	m_u	1.660 540 2(10)	10^{-27} kg	0.59
in electron volts, $m_u c^2/\{e\}$		931.494 32(28)	MeV	0.30
Faraday constant, $N_A e$	F	96 485.309(29)	C mol^{-1}	0.30
molar Planck constant	$N_A h$	3.990 313 23(36)	10^{-10} J s mol^{-1}	0.089
	$N_A hc$	0.119 626 58(11)	J m mol^{-1}	0.089
molar gas constant	R	8.314 510(70)	J mol^{-1} K^{-1}	8.4
Boltzmann constant, R/N_A	k	1.380 658(12)	10^{-23} J K^{-1}	8.5
in electron volts, $k/\{e\}$		8.617 385(73)	10^{-5} eV K^{-1}	8.4
in hertz, k/h		2.083 674(18)	10^{10} Hz K^{-1}	8.4
in wavenumbers, k/hc		69.503 87(59)	m^{-1} K^{-1}	8.4
molar volume (ideal gas), RT/p $T=273.15$ K, $p=101\,325$ Pa	V_m	0.022 414 10(19)	m^3 mol^{-1}	8.4
Loschmidt constant, N_A/V_m	n_0	2.686 763(23)	10^{25} m^{-3}	8.5
$T=273.15$ K, $p=100$ kPa	V_m	0.022 711 08(19)	m^3 mol^{-1}	8.4
Sackur-Tetrode constant (absolute entropy constant),[b] $\frac{5}{2}+\ln[(2\pi m_u kT_1/h^2)^{3/2} kT_1/p_0]$ $T_1=1$ K, $p_0=100$ kPa	S_0/R	−1.151 693(21)		18
$p_0=101\,325$ Pa		−1.164 856(21)		18
Stefan-Boltzmann constant, $(\pi^2/60)k^4/\hbar^3c^2$	σ	5.670 51(19)	10^{-8} W m^{-2} K^{-4}	34
first radiation constant, $2\pi hc^2$	c_1	3.741 774 9(22)	10^{-16} W m^2	0.60

TABLE 2. (*Continued*).

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
PHYSICO-CHEMICAL CONSTANTS (*Continued*)				
second radiation constant, hc/k	c_2	0.014 387 69(12)	m K	8.4
Wien displacement law constant, $b=\lambda_{\max}T=c_2/4.965\,114\,23\ldots$	b	2.897 756(24)	10^{-3} m K	8.4

[a] The scalar magnitude of the neutron moment is listed here. The neutron magnetic dipole is directed oppositely to that of the proton, and corresponds to the dipole associated with a spinning negative charge distribution. The vector sum, $\mu_d=\mu_p+\mu_n$, is approximately satisfied.

[b] The entropy of an ideal monatomic gas of relative atomic weight A_r is given by

$$S=S_0+\tfrac{3}{2}R\ \ln A_r-R\ \ln(p/p_0)+\tfrac{5}{2}R\ \ln(T/\mathrm{K})\ .$$

TABLE 3. Maintained units and standard values. A summary of "maintained" units and "standard" values and their relationship to SI units, based on a least-squares adjustment with 17 degrees of freedom. The digits in parentheses are the one-standard-deviation uncertainty in the last digits of the given value. Since the uncertainties of many of these entries are correlated, the full variance matrix must be used in evluating the uncertainties of quantities computed from them.

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
electron volt, $(e/\mathrm{C})\mathrm{J}=\{e\}\mathrm{J}$	eV	1.602 177 33(49)	10^{-19} J	0.30
(unified) atomic mass unit, $1\ \mathrm{u}=m_u=\frac{1}{12}m(^{12}\mathrm{C})$	u	1.660 540 2(10)	10^{-27} kg	0.59
standard atmosphere	atm	101 325	Pa	(exact)
standard acceleration of gravity	g_n	9.806 65	m s^{-2}	(exact)
"As-maintained" electrical units				
BIPM maintained ohm, $\Omega_{69-\mathrm{BI}}$, $\Omega_{\mathrm{BI85}}\equiv\Omega_{69-\mathrm{BI}}$(January 1, 1985)	Ω_{BI85}	$1-1.563(50)\times10^{-6}=0.999\,998\,437(50)$	Ω	0.050
Drift rate of $\Omega_{69-\mathrm{BI}}$	$\frac{d\Omega_{69-\mathrm{BI}}}{dt}$	−0.056 6(15)	μΩ/a	
BIPM maintained volt, $\mathrm{V}_{76-\mathrm{BI}}=483\,594.0\ \mathrm{GHz}(h/2e)$	$\mathrm{V}_{76-\mathrm{BI}}$	$1-7.59(30)\times10^{-6}=0.999\,992\,41(30)$	V	0.30
BIPM maintained ampere, $\mathrm{A}_{\mathrm{BIPM}}=\mathrm{V}_{76-\mathrm{BI}}/\Omega_{69-\mathrm{BI}}$	$\mathrm{A}_{\mathrm{BI85}}$	$1-6.03(30)\times10^{-6}=0.999\,993\,97(30)$	A	0.30
X-ray standards				
Cu x unit: $\lambda(\mathrm{CuK}\alpha_1)\equiv1537.400$ xu	xu($\mathrm{CuK}\alpha_1$)	1.002 077 89(70)	10^{-13} m	0.70
Mo x unit: $\lambda(\mathrm{MoK}\alpha_1)\equiv707.831$ xu	xu($\mathrm{MoK}\alpha_1$)	1.002 099 38(45)	10^{-13} m	0.45
Å*: $\lambda(\mathrm{WK}\alpha_1)\equiv0.209\,100$ Å*	Å*	1.000 014 81(92)	10^{-10} m	0.92
lattice spacing of Si (in vacuum, 22.5 °C),[a]	a	0.543 101 96(11)	nm	0.21
$d_{220}=a/\sqrt{8}$	d_{220}	0.192 015 540(40)	nm	0.21
molar volume of Si, $M(\mathrm{Si})/\rho(\mathrm{Si})=N_A a^3/8$	V_m(Si)	12.058 817 9(89)	cm^3/mol	0.74

[a] The lattice spacing of single-crystal Si can vary by parts in 10^7 depending on the preparation process. Measurements at PTB indicate also the possibility of distortions from exact cubic symmetry of the order of 0.2 ppm.

TABLE 4. Energy conversion factors. To use this table note that all entries on the same line are equal; the unit at the top of a column applies to all of the values beneath it. Example: 1 eV = 806 544.10 m^{-1} = 11 604.45 K.

	J	kg	m^{-1}	Hz
1 J =	1	$1/\{c^2\}$ $1.112\,650\,06 \times 10^{-17}$	$1/\{hc\}$ $5.034\,112\,5(30) \times 10^{24}$	$1/\{h\}$ $1.509\,188\,97(90) \times 10^{33}$
1 kg =	$\{c^2\}$ $8.987\,551\,787 \times 10^{16}$	1	$\{c/h\}$ $4.524\,434\,7(27) \times 10^{41}$	$\{c^2/h\}$ $1.356\,391\,40(81) \times 10^{50}$
1 m^{-1} =	$\{hc\}$ $1.986\,447\,5(12) \times 10^{-25}$	$\{h/c\}$ $2.210\,220\,9(13) \times 10^{-42}$	1	$\{c\}$ $299\,792\,458$
1 Hz =	$\{h\}$ $6.626\,075\,5(40) \times 10^{-34}$	$\{h/c^2\}$ $7.372\,503\,2(44) \times 10^{-51}$	$1/\{c\}$ $3.335\,640\,952 \times 10^{-9}$	1
1 K =	$\{k\}$ $1.380\,658(12) \times 10^{-23}$	$\{k/c^2\}$ $1.536\,189(13) \times 10^{-40}$	$\{k/hc\}$ $69.503\,87(59)$	$\{k/h\}$ $2.083\,674(18) \times 10^{10}$
1 eV =	$\{e\}$ $1.602\,177\,33(49) \times 10^{-19}$	$\{e/c^2\}$ $1.782\,662\,70(54) \times 10^{-36}$	$\{e/hc\}$ $806\,554.10(24)$	$\{e/h\}$ $2.417\,988\,36(72) \times 10^{14}$
1 eV =	$\{m_u c^2\}$ $1.492\,419\,09(88) \times 10^{-10}$	$\{m_u\}$ $1.660\,540\,2(10) \times 10^{-27}$	$\{m_u c/h\}$ $7.153\,005\,63(67) \times 10^{14}$	$\{m_u c^2/h\}$ $2.252\,342\,42(20) \times 10^{23}$
1 hartree =	$\{2R_\infty hc\}$ $4.359\,748\,2(26) \times 10^{-18}$	$\{2R_\infty h/c\}$ $4.850\,874\,1(29) \times 10^{-35}$	$\{2R_\infty\}$ $21\,974\,463.067(26)$	$\{2R_\infty c\}$ $6.579\,683\,899\,9(78) \times 10^{15}$
	K	eV	u	hartree
1 J =	$1/\{k\}$ $7.242\,924(61) \times 10^{22}$	$1/\{e\}$ $6.241\,506\,4(19) \times 10^{18}$	$1/\{m_u c^2\}$ $6.700\,530\,8(40) \times 10^{9}$	$1/\{2R_\infty hc\}$ $2.293\,710\,4(14) \times 10^{17}$
1 kg =	$\{c^2/k\}$ $6.509\,616(55) \times 10^{39}$	$\{c^2/e\}$ $5.609\,586\,2(17) \times 10^{35}$	$1/\{m_u\}$ $6.022\,136\,7(36) \times 10^{26}$	$\{c/2R_\infty h\}$ $2.061\,484\,1(12) \times 10^{34}$
1 m^{-1} =	$\{hc/k\}$ $0.014\,387\,69(12)$	$\{hc/e\}$ $1.239\,842\,44(37) \times 10^{-6}$	$\{h/m_u c\}$ $1.331\,025\,22(12) \times 10^{-15}$	$1/\{2R\infty\}$ $4.556\,335\,267\,2(54) \times 10^{-8}$
1 Hz =	$\{h/k\}$ $4.799\,216(41) \times 10^{-11}$	$\{h/e\}$ $4.135\,669\,2(12) \times 10^{-15}$	$\{h/m_u c^2\}$ $4.439\,822\,24(40) \times 10^{-24}$	$1/\{2R_\infty c\}$ $1.519\,829\,850\,8(18) \times 10^{16}$
1 K =	1	$\{k/e\}$ $8.617\,385(73) \times 10^{-5}$	$\{k/m_u c^2\}$ $9.251\,140(78) \times 10^{-14}$	$\{k/2R_\infty hc\}$ $3.166\,829(27) \times 10^{-6}$
1 eV =	$\{e/k\}$ $11\,604.45(10)$	1	$\{e/m_u c^2\}$ $1.073\,543\,85(33) \times 10^{-9}$	$\{e/2R_\infty hc\}$ $0.036\,749\,309(11)$
1 u =	$\{m_u c^2/k\}$ $1.080\,947\,8(91) \times 10^{13}$	$\{m_u c^2/e\}$ $931.494\,32(28) \times 10^{6}$	1	$\{m_u c/2R_\infty h\}$ $3.423\,177\,25(31) \times 10^{7}$
1 hartree =	$\{2R_\infty hc/k\}$ $3.157\,733(27) \times 10^{5}$	$\{2R_\infty hc/e\}$ $27.211\,396(81)$	$\{2R_\infty h/m_u c\}$ $2.921\,262\,69(26) \times 10^{-8}$	1

TABLE 5. Expanded matrix of variances, covariances, and correlation coefficients for the 1986 recommended set of fundamental physical constants. The elements of the variance matrix appear on and above the major diagonal in (parts in 10^9)^2; correlation coefficients appear in *italics* below the diagonal. The values are given to as many as six digits only as a matter of consistency. The correlation coefficient between m_e and N_A appears as − 1.000 in this table because the auxiliary constants were considered to be exact in carrying out the least-squares adjustment. When the uncertainties of m_p/m_e and M_p are properly taken into account, the correlation coefficient is − 0.999 and the variances of m_e and N_A are slightly increased.

	α^{-1}	K_V	K_Ω	μ_μ/μ_p	e	h	m_e	N_A	F
α^{-1}	1 997	−1 062	925	3 267	−3 059	−4 121	−127	127	−2 932
K_V	*−0.080*	87 988	90	−1 737	89 050	177 038	174 914	−174 914	−85 864
K_Ω	*0.416*	*0.006*	2 477	1 513	−835	−744	1 105	−1 105	−1 939
μ_μ/μ_p	*0.498*	*−0.040*	*0.207*	21 523	−5 004	−6 742	−208	208	−4 796
e	*−0.226*	*0.989*	*−0.055*	*−0.112*	92 109	181 159	175 042	−175 042	−82 933
h	*−0.154*	*0.997*	*−0.025*	*−0.077*	*0.997*	358 197	349 956	−349 956	−168 797
m_e	*−0.005*	*0.997*	*0.038*	*−0.002*	*0.975*	*0.989*	349 702	−349 702	−174 660
N_A	*0.005*	*−0.997*	*−0.038*	*0.002*	*−0.975*	*−0.989*	*−1.000*	349 702	174 660
F	*−0.217*	*−0.956*	*−0.129*	*−0.108*	*−0.902*	*−0.931*	*−0.975*	*0.975*	91 727

References

[1] E. R. Cohen and B. N. Taylor, "The 1986 Adjustment of the Fundamental Physical Constants, a Report of the CODATA Task group on Fundamental Constants," CODATA Bulletin No. 63 (Pergamon, Fairview Park, Elmsford, NY 10523, or Headington Hill Hall, Oxford OX3 OBW, U.K., 1986).

[2] E. R. Cohen and B. N. Taylor, Rev. Mod. Phys. **59**, 1121 (1987).

[3] Recommended Consistent Values of the Fundamental Physical Constants, 1973, a Report of the CODATA Task Group on Fundamental Constants, CODATA Bulletin No. 11, CODATA Secretariat, 51 Blvd. de Monmorency, 75016 Paris, France, August, 1973.

[4] E. R. Cohen and B. N. Taylor, J. Phys. Chem. Ref. Data **2**, 663 (1973).