REVIEWS OF MODERN PHYSICS, VOLUME 80, APRIL–JUNE 2008

CODATA recommended values of the fundamental physical constants: 2006*

Peter J. Mohr,† Barry N. Taylor,‡ and David B. Newell§

National Institute of Standards and Technology, Gaithersburg,
Maryland 20899-8420, USA

(Published 6 June 2008)

This paper gives the 2006 self-consistent set of values of the basic constants and conversion factors of physics and chemistry recommended by the Committee on Data for Science and Technology (CODATA) for international use. Further, it describes in detail the adjustment of the values of the constants, including the selection of the final set of input data based on the results of least-squares analyses. The 2006 adjustment takes into account the data considered in the 2002 adjustment as well as the data that became available between 31 December 2002, the closing date of that adjustment, and 31 December 2006, the closing date of the new adjustment. The new data have led to a significant reduction in the uncertainties of many recommended values. The 2006 set replaces the previously recommended 2002 CODATA set and may also be found on the World Wide Web at physics.nist.gov/constants.

DOI: 10.1103/RevModPhys.80.633 PACS number(s): 06.20.Jr, 12.20.−m

CONTENTS

---

*This report was prepared by the authors under the auspices of the CODATA Task Group on Fundamental Constants. The members of the task group are:
F. Cabiati, Istituto Nazionale di Ricerca Metrologica, Italy
K. Fujii, National Metrology Institute of Japan, Japan
S. G. Karshenboim, D. I. Mendeleyev All-Russian Research Institute for Metrology, Russian Federation
I. Lindgren, Chalmers University of Technology and Göteborg University, Sweden
B. A. Mamyrin (deceased), A. F. Ioffe Physical-Technical Institute, Russian Federation
W. Martienssen, Johann Wolfgang Goethe-Universität, Germany
P. J. Mohr, National Institute of Standards and Technology, United States of America
D. B. Newell, National Institute of Standards and Technology, United States of America
F. Nez, Laboratoire Kastler-Brossel, France
B. W. Petley, National Physical Laboratory, United Kingdom
T. J. Quinn, Bureau international des poids et mesures
B. N. Taylor, National Institute of Standards and Technology, United States of America
W. Wöger, Physikalisch-Technische Bundesanstalt, Germany
B. M. Wood, National Research Council, Canada
Z. Zhang, National Institute of Metrology, China (People's Republic of)
This review is being published simultaneously by the Journal of Physical and Chemical Reference Data.

†mohr@nist.gov
‡barry.taylor@nist.gov
§dnewell@nist.gov

0034-6861/2008/80(2)/633(98)

TABLE XLVII. Summary of the results of several least-squares adjustments carried out to investigate the effect of assuming the relations for K_J and R_K given in Eqs. (372) and (373). The values of α, h, ε_K, and ε_J are those obtained in the indicated adjustments. The quantity $R_B=\sqrt{\chi^2/\nu}$ is the Birge ratio and r_i is the normalized residual of the indicated input datum (see Table XXX). These four data have the largest $|r_i|$ of all the input data and are the only data in Adj. (i) with $|r_i|>1.50$. See the text for an explanation and discussion of each adjustment, but in brief, (i) assumes $K_J=2e/h$ and $R_K=h/e^2$ and uses all the data; (ii) is (i) with the relation $K_J=2e/h$ relaxed; (iii) is (i) with the relation $R_K=h/e^2$ relaxed; (iv) is (i) with both relations relaxed; (v) is (iv) with the $V_m(\mathrm{Si})$ datum deleted; (vi) is (iv) with the $\Gamma'_{p-90}(\mathrm{lo})$ and $\Gamma'_{h-90}(\mathrm{lo})$ data deleted; and (vii) is (iv) with the $V_m(\mathrm{Si})$, $\Gamma'_{p-90}(\mathrm{lo})$, and $\Gamma'_{h-90}(\mathrm{lo})$ data deleted.

Adj.	R_B	α^{-1}	$h/(\mathrm{J\,s})$	ε_K	ε_J	r_{B53}	r_{B55}	r_{B39}	$r_{B31.1}$
(i)	1.14	137.035 999 687(93)	$6.626\,068\,96(22)\times10^{-34}$	0	0	−2.82	−2.71	2.37	2.31
(ii)	1.14	137.035 999 688(93)	$6.626\,0682(10)\times10^{-34}$	0	$-61(79)\times10^{-9}$	−3.22	−2.75	2.39	1.77
(iii)	1.14	137.035 999 683(93)	$6.626\,069\,06(25)\times10^{-34}$	$16(18)\times10^{-9}$	0	−2.77	−2.71	2.36	2.45
(iv)	1.14	137.035 999 685(93)	$6.626\,0681(11)\times10^{-34}$	$20(18)\times10^{-9}$	$-77(80)\times10^{-9}$	−3.27	−2.75	2.39	1.79
(v)	1.05	137.035 999 686(93)	$6.626\,0653(13)\times10^{-34}$	$23(18)\times10^{-9}$	$-281(95)\times10^{-9}$	Deleted	−2.45	2.19	0.01
(vi)	1.05	137.035 999 686(93)	$6.626\,0744(19)\times10^{-34}$	$24(18)\times10^{-9}$	$407(143)\times10^{-9}$	−0.05	−2.45	2.19	Deleted
(vii)	1.06	137.035 999 686(93)	$6.626\,0722(95)\times10^{-34}$	$24(18)\times10^{-9}$	$238(720)\times10^{-9}$	Deleted	−2.45	2.19	Deleted

TABLE XLVIII. An abbreviated list of the CODATA recommended values of the fundamental constants of physics and chemistry based on the 2006 adjustment.

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
speed of light in vacuum	c, c_0	299 792 458	$\mathrm{m\,s^{-1}}$	(Exact)
magnetic constant	μ_0	$4\pi\times10^{-7}$	$\mathrm{N\,A^{-2}}$	
		$=12.566\,370\,614\ldots\times10^{-7}$	$\mathrm{N\,A^{-2}}$	(Exact)
electric constant $1/\mu_0c^2$	ϵ_0	$8.854\,187\,817\ldots\times10^{-12}$	$\mathrm{F\,m^{-1}}$	(Exact)
Newtonian constant of gravitation	G	$6.674\,28(67)\times10^{-11}$	$\mathrm{m^3\,kg^{-1}\,s^{-2}}$	1.0×10^{-4}
Planck constant	h	$6.626\,068\,96(33)\times10^{-34}$	J s	5.0×10^{-8}
$h/2\pi$	$\hbar$	$1.054\,571\,628(53)\times10^{-34}$	J s	5.0×10^{-8}
elementary charge	e	$1.602\,176\,487(40)\times10^{-19}$	C	2.5×10^{-8}
magnetic flux quantum $h/2e$	Φ_0	$2.067\,833\,667(52)\times10^{-15}$	Wb	2.5×10^{-8}
conductance quantum $2e^2/h$	G_0	$7.748\,091\,7004(53)\times10^{-5}$	S	6.8×10^{-10}
electron mass	m_e	$9.109\,382\,15(45)\times10^{-31}$	kg	5.0×10^{-8}
proton mass	m_p	$1.672\,621\,637(83)\times10^{-27}$	kg	5.0×10^{-8}
proton-electron mass ratio	m_p/m_e	1836.152 672 47(80)		4.3×10^{-10}
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,5376(50)\times10^{-3}$		6.8×10^{-10}
inverse fine-structure constant	α^{-1}	137.035 999 679(94)		6.8×10^{-10}
Rydberg constant $\alpha^2m_ec/2h$	R_∞	10 973 731.568 527(73)	$\mathrm{m^{-1}}$	6.6×10^{-12}
Avogadro constant	N_A, L	$6.022\,141\,79(30)\times10^{23}$	$\mathrm{mol^{-1}}$	5.0×10^{-8}
Faraday constant N_Ae	F	96 485.3399(24)	$\mathrm{C\,mol^{-1}}$	2.5×10^{-8}
molar gas constant	R	8.314 472(15)	$\mathrm{J\,mol^{-1}\,K^{-1}}$	1.7×10^{-6}
Boltzmann constant R/N_A	k	$1.380\,6504(24)\times10^{-23}$	$\mathrm{J\,K^{-1}}$	1.7×10^{-6}
Stefan-Boltzmann constant $(\pi^2/60)k^4/\hbar^3c^2$	σ	$5.670\,400(40)\times10^{-8}$	$\mathrm{W\,m^{-2}\,K^{-4}}$	7.0×10^{-6}
		Non-SI units accepted for use with the SI		
electron volt: (e/C) J	eV	$1.602\,176\,487(40)\times10^{-19}$	J	2.5×10^{-8}
(unified) atomic mass unit $1\ \mathrm{u}=m_u=\frac{1}{12}m(^{12}\mathrm{C})$ $=10^{-3}\ \mathrm{kg\,mol^{-1}}/N_A$	u	$1.660\,538\,782(83)\times10^{-27}$	kg	5.0×10^{-8}

TABLE XLIX. The CODATA recommended values of the fundamental constants of physics and chemistry based on the 2006 adjustment.

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
		UNIVERSAL		
speed of light in vacuum	c, c_0	299 792 458	$\mathrm{m\,s^{-1}}$	(Exact)
magnetic constant	μ_0	$4\pi\times10^{-7}$	$\mathrm{N\,A^{-2}}$	
		$=12.566\,370\,614\ldots\times10^{-7}$	$\mathrm{N\,A^{-2}}$	(Exact)
electric constant $1/\mu_0c^2$	ϵ_0	$8.854\,187\,817\ldots\times10^{-12}$	$\mathrm{F\,m^{-1}}$	(Exact)
characteristic impedance of vacuum $\sqrt{\mu_0/\epsilon_0}=\mu_0c$	Z_0	$376.730\,313\,461\ldots$	Ω	(Exact)
Newtonian constant of gravitation	G	$6.674\,28(67)\times10^{-11}$	$\mathrm{m^3\,kg^{-1}\,s^{-2}}$	1.0×10^{-4}
	$G/\hbar c$	$6.708\,81(67)\times10^{-39}$	$(\mathrm{GeV}/c^2)^{-2}$	1.0×10^{-4}
Planck constant	h	$6.626\,068\,96(33)\times10^{-34}$	J s	5.0×10^{-8}
in eV s		$4.135\,667\,33(10)\times10^{-15}$	eV s	2.5×10^{-8}
$h/2\pi$	$\hbar$	$1.054\,571\,628(53)\times10^{-34}$	J s	5.0×10^{-8}
in eV s		$6.582\,118\,99(16)\times10^{-16}$	eV s	2.5×10^{-8}
$\hbar c$ in MeV fm		197.326 9631(49)	MeV fm	2.5×10^{-8}
Planck mass $(\hbar c/G)^{1/2}$	m_P	$2.176\,44(11)\times10^{-8}$	kg	5.0×10^{-5}
energy equivalent in GeV	$m_\mathrm{P}c^2$	$1.220\,892(61)\times10^{19}$	GeV	5.0×10^{-5}
Planck temperature $(\hbar c^5/G)^{1/2}/k$	T_P	$1.416\,785(71)\times10^{32}$	K	5.0×10^{-5}
Planck length $\hbar/m_\mathrm{P}c=(\hbar G/c^3)^{1/2}$	l_P	$1.616\,252(81)\times10^{-35}$	m	5.0×10^{-5}
Planck time $l_\mathrm{P}/c=(\hbar G/c^5)^{1/2}$	t_P	$5.391\,24(27)\times10^{-44}$	s	5.0×10^{-5}
		ELECTROMAGNETIC		
elementary charge	e	$1.602\,176\,487(40)\times10^{-19}$	C	2.5×10^{-8}
	e/h	$2.417\,989\,454(60)\times10^{14}$	$\mathrm{A\,J^{-1}}$	2.5×10^{-8}
magnetic flux quantum $h/2e$	Φ_0	$2.067\,833\,667(52)\times10^{-15}$	Wb	2.5×10^{-8}
conductance quantum $2e^2/h$	G_0	$7.748\,091\,7004(53)\times10^{-5}$	S	6.8×10^{-10}
inverse of conductance quantum	G_0^{-1}	12 906.403 7787(88)	Ω	6.8×10^{-10}
Joesphson constant[a] $2e/h$	K_J	$483\,597.891(12)\times10^{9}$	$\mathrm{Hz\,V^{-1}}$	2.5×10^{-8}
von Klitzing constant[b] $h/e^2=\mu_0c/2\alpha$	R_K	25 812.807 557(18)	Ω	6.8×10^{-10}
Bohr magneton $e\hbar/2m_\mathrm{e}$	μ_B	$927.400\,915(23)\times10^{-26}$	$\mathrm{J\,T^{-1}}$	2.5×10^{-8}
in $\mathrm{eV\,T^{-1}}$		$5.788\,381\,7555(79)\times10^{-5}$	$\mathrm{eV\,T^{-1}}$	1.4×10^{-9}
	μ_B/h	$13.996\,246\,04(35)\times10^{9}$	$\mathrm{Hz\,T^{-1}}$	2.5×10^{-8}
	μ_B/hc	46.686 4515(12)	$\mathrm{m^{-1}\,T^{-1}}$	2.5×10^{-8}
	μ_B/k	0.671 7131(12)	$\mathrm{K\,T^{-1}}$	1.7×10^{-6}
nuclear magneton $e\hbar/2m_\mathrm{p}$	μ_N	$5.050\,783\,24(13)\times10^{-27}$	$\mathrm{J\,T^{-1}}$	2.5×10^{-8}
in $\mathrm{eV\,T^{-1}}$		$3.152\,451\,2326(45)\times10^{-8}$	$\mathrm{eV\,T^{-1}}$	1.4×10^{-9}
	μ_N/h	7.622 593 84(19)	$\mathrm{MHz\,T^{-1}}$	2.5×10^{-8}
	μ_N/hc	$2.542\,623\,616(64)\times10^{-2}$	$\mathrm{m^{-1}\,T^{-1}}$	2.5×10^{-8}
	μ_N/k	$3.658\,2637(64)\times10^{-4}$	$\mathrm{K\,T^{-1}}$	1.7×10^{-6}
		ATOMIC AND NUCLEAR		
		General		
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,5376(50)\times10^{-3}$		6.8×10^{-10}
inverse fine-structure constant	α^{-1}	137.035 999 679(94)		6.8×10^{-10}
Rydberg constant $\alpha^2m_\mathrm{e}c/2h$	R_∞	10 973 731.568 527(73)	$\mathrm{m^{-1}}$	6.6×10^{-12}
	$R_\infty c$	$3.289\,841\,960\,361(22)\times10^{15}$	Hz	6.6×10^{-12}

TABLE XLIX. (*Continued.*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
	$R_\infty hc$	$2.179\,871\,97(11)\times 10^{-18}$	J	5.0×10^{-8}
$R_\infty hc$ in eV		$13.605\,691\,93(34)$	eV	2.5×10^{-8}
Bohr radius $\alpha/4\pi R_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2$	a_0	$0.529\,177\,208\,59(36)\times 10^{-10}$	m	6.8×10^{-10}
Hartree energy $e^2/4\pi\epsilon_0 a_0 = 2R_\infty hc = \alpha^2 m_e c^2$	E_h	$4.359\,743\,94(22)\times 10^{-18}$	J	5.0×10^{-8}
in eV		$27.211\,383\,86(68)$	eV	2.5×10^{-8}
quantum of circulation	$h/2m_e$	$3.636\,947\,5199(50)\times 10^{-4}$	$m^2\,s^{-1}$	1.4×10^{-9}
	h/m_e	$7.273\,895\,040(10)\times 10^{-4}$	$m^2\,s^{-1}$	1.4×10^{-9}
		Electroweak		
Fermi coupling constant[c]	$G_F/(\hbar c)^3$	$1.166\,37(1)\times 10^{-5}$	GeV^{-2}	8.6×10^{-6}
weak mixing angle[d] θ_W (on-shell scheme) $\sin^2\theta_W = s_W^2 \equiv 1-(m_W/m_Z)^2$	$\sin^2\theta_W$	$0.222\,55(56)$		2.5×10^{-3}
		Electron, e^-		
electron mass	m_e	$9.109\,382\,15(45)\times 10^{-31}$	kg	5.0×10^{-8}
in u, $m_e = A_r(e)$ u (electron relative atomic mass times u)		$5.485\,799\,0943(23)\times 10^{-4}$	u	4.2×10^{-10}
energy equivalent	$m_e c^2$	$8.187\,104\,38(41)\times 10^{-14}$	J	5.0×10^{-8}
in MeV		$0.510\,998\,910(13)$	MeV	2.5×10^{-8}
electron-muon mass ratio	m_e/m_μ	$4.836\,331\,71(12)\times 10^{-3}$		2.5×10^{-8}
electron-tau mass ratio	m_e/m_τ	$2.875\,64(47)\times 10^{-4}$		1.6×10^{-4}
electron-proton mass ratio	m_e/m_p	$5.446\,170\,2177(24)\times 10^{-4}$		4.3×10^{-10}
electron-neutron mass ratio	m_e/m_n	$5.438\,673\,4459(33)\times 10^{-4}$		6.0×10^{-10}
electron-deuteron mass ratio	m_e/m_d	$2.724\,437\,1093(12)\times 10^{-4}$		4.3×10^{-10}
electron to α particle mass ratio	m_e/m_α	$1.370\,933\,555\,70(58)\times 10^{-4}$		4.2×10^{-10}
electron charge to mass quotient	$-e/m_e$	$-1.758\,820\,150(44)\times 10^{11}$	$C\,kg^{-1}$	2.5×10^{-8}
electron molar mass $N_A m_e$	$M(e), M_e$	$5.485\,799\,0943(23)\times 10^{-7}$	$kg\,mol^{-1}$	4.2×10^{-10}
Compton wavelength $h/m_e c$	λ_C	$2.426\,310\,2175(33)\times 10^{-12}$	m	1.4×10^{-9}
$\lambda_C/2\pi = \alpha a_0 = \alpha^2/4\pi R_\infty$	$\bar{\lambda}_C$	$386.159\,264\,59(53)\times 10^{-15}$	m	1.4×10^{-9}
classical electron radius $\alpha^2 a_0$	r_e	$2.817\,940\,2894(58)\times 10^{-15}$	m	2.1×10^{-9}
Thomson cross section $(8\pi/3)r_e^2$	σ_e	$0.665\,245\,8558(27)\times 10^{-28}$	m^2	4.1×10^{-9}
electron magnetic moment	μ_e	$-928.476\,377(23)\times 10^{-26}$	$J\,T^{-1}$	2.5×10^{-8}
to Bohr magneton ratio	μ_e/μ_B	$-1.001\,159\,652\,181\,11(74)$		7.4×10^{-13}
to nuclear magneton ratio	μ_e/μ_N	$-1838.281\,970\,92(80)$		4.3×10^{-10}
electron magnetic moment anomaly $\lvert\mu_e\rvert/\mu_B - 1$	a_e	$1.159\,652\,181\,11(74)\times 10^{-3}$		6.4×10^{-10}
electron g-factor $-2(1+a_e)$	g_e	$-2.002\,319\,304\,3622(15)$		7.4×10^{-13}
electron-muon magnetic moment ratio	μ_e/μ_μ	$206.766\,9877(52)$		2.5×10^{-8}
electron-proton magnetic moment ratio	μ_e/μ_p	$-658.210\,6848(54)$		8.1×10^{-9}
electron to shielded proton magnetic moment ratio (H_2O, sphere, 25 °C)	μ_e/μ_p'	$-658.227\,5971(72)$		1.1×10^{-8}
electron-neutron magnetic moment ratio	μ_e/μ_n	$960.920\,50(23)$		2.4×10^{-7}
electron-deuteron magnetic moment ratio	μ_e/μ_d	$-2143.923\,498(18)$		8.4×10^{-9}

TABLE XLIX. (*Continued.*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
electron to shielded helion magnetic moment ratio (gas, sphere, 25 °C)	$\mu_\mathrm{e}/\mu'_\mathrm{h}$	864.058 257(10)		1.2×10^{-8}
electron gyromagnetic ratio $2\lvert\mu_\mathrm{e}\rvert/\hbar$	γ_e	1.760 859 770(44) $\times10^{11}$	$\mathrm{s^{-1}\,T^{-1}}$	2.5×10^{-8}
	$\gamma_\mathrm{e}/2\pi$	28 024.953 64(70)	$\mathrm{MHz\,T^{-1}}$	2.5×10^{-8}
		Muon, μ^-		
muon mass	m_μ	1.883 531 30(11) $\times10^{-28}$	kg	5.6×10^{-8}
in u, $m_\mu=A_\mathrm{r}(\mu)$ u (muon relative atomic mass times u)		0.113 428 9256(29)	u	2.5×10^{-8}
energy equivalent	$m_\mu c^2$	1.692 833 510(95) $\times10^{-11}$	J	5.6×10^{-8}
in MeV		105.658 3668(38)	MeV	3.6×10^{-8}
muon-electron mass ratio	m_μ/m_e	206.768 2823(52)		2.5×10^{-8}
muon-tau mass ratio	m_μ/m_τ	5.945 92(97) $\times10^{-2}$		1.6×10^{-4}
muon-proton mass ratio	m_μ/m_p	0.112 609 5261(29)		2.5×10^{-8}
muon-neutron mass ratio	m_μ/m_n	0.112 454 5167(29)		2.5×10^{-8}
muon molar mass $N_\mathrm{A}m_\mu$	$M(\mu), M_\mu$	0.113 428 9256(29) $\times10^{-3}$	$\mathrm{kg\,mol^{-1}}$	2.5×10^{-8}
muon Compton wavelength $h/m_\mu c$	$\lambda_{\mathrm{C},\mu}$	11.734 441 04(30) $\times10^{-15}$	m	2.5×10^{-8}
$\lambda_{\mathrm{C},\mu}/2\pi$	$\bar{\lambda}_{\mathrm{C},\mu}$	1.867 594 295(47) $\times10^{-15}$	m	2.5×10^{-8}
muon magnetic moment	μ_μ	−4.490 447 86(16) $\times10^{-26}$	$\mathrm{J\,T^{-1}}$	3.6×10^{-8}
to Bohr magneton ratio	μ_μ/μ_B	−4.841 970 49(12) $\times10^{-3}$		2.5×10^{-8}
to nuclear magneton ratio	μ_μ/μ_N	−8.890 597 05(23)		2.5×10^{-8}
muon magnetic moment anomaly $\lvert\mu_\mu\rvert/(e\hbar/2m_\mu)-1$	a_μ	1.165 920 69(60) $\times10^{-3}$		5.2×10^{-7}
muon g-factor $-2(1+a_\mu)$	g_μ	−2.002 331 8414(12)		6.0×10^{-10}
muon-proton magnetic moment ratio	μ_μ/μ_p	−3.183 345 137(85)		2.7×10^{-8}
		Tau, τ^-		
tau mass[e]	m_τ	3.167 77(52) $\times10^{-27}$	kg	1.6×10^{-4}
in u, $m_\tau=A_\mathrm{r}(\tau)$ u (tau relative atomic mass times u)		1.907 68(31)	u	1.6×10^{-4}
energy equivalent	$m_\tau c^2$	2.847 05(46) $\times10^{-10}$	J	1.6×10^{-4}
in MeV		1776.99(29)	MeV	1.6×10^{-4}
tau-electron mass ratio	m_τ/m_e	3477.48(57)		1.6×10^{-4}
tau-muon mass ratio	m_τ/m_μ	16.8183(27)		1.6×10^{-4}
tau-proton mass ratio	m_τ/m_p	1.893 90(31)		1.6×10^{-4}
tau-neutron mass ratio	m_τ/m_n	1.891 29(31)		1.6×10^{-4}
tau molar mass $N_\mathrm{A}m_\tau$	$M(\tau), M_\tau$	1.907 68(31) $\times10^{-3}$	$\mathrm{kg\,mol^{-1}}$	1.6×10^{-4}
tau Compton wavelength $h/m_\tau c$	$\lambda_{\mathrm{C},\tau}$	0.697 72(11) $\times10^{-15}$	m	1.6×10^{-4}
$\lambda_{\mathrm{C},\tau}/2\pi$	$\bar{\lambda}_{\mathrm{C},\tau}$	0.111 046(18) $\times10^{-15}$	m	1.6×10^{-4}
		Proton, p		
proton mass	m_p	1.672 621 637(83) $\times10^{-27}$	kg	5.0×10^{-8}
in u, $m_\mathrm{p}=A_\mathrm{r}(\mathrm{p})$ u (proton relative atomic mass times u)		1.007 276 466 77(10)	u	1.0×10^{-10}
energy equivalent	$m_\mathrm{p}c^2$	1.503 277 359(75) $\times10^{-10}$	J	5.0×10^{-8}
in MeV		938.272 013(23)	MeV	2.5×10^{-8}
proton-electron mass ratio	$m_\mathrm{p}/m_\mathrm{e}$	1836.152 672 47(80)		4.3×10^{-10}
proton-muon mass ratio	m_p/m_μ	8.880 243 39(23)		2.5×10^{-8}
proton-tau mass ratio	m_p/m_τ	0.528 012(86)		1.6×10^{-4}

TABLE XLIX. (*Continued.*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
proton-neutron mass ratio	m_p/m_n	0.998 623 478 24(46)		4.6×10^{-10}
proton charge to mass quotient	e/m_p	$9.578\,833\,92(24)\times10^{7}$	C kg^{-1}	2.5×10^{-8}
proton molar mass $N_A m_p$	$M(\mathrm{p}), M_p$	$1.007\,276\,466\,77(10)\times10^{-3}$	kg mol^{-1}	1.0×10^{-10}
proton Compton wavelength $h/m_p c$	$\lambda_{C,p}$	$1.321\,409\,8446(19)\times10^{-15}$	m	1.4×10^{-9}
$\lambda_{C,p}/2\pi$	$\lambdabar_{C,p}$	$0.210\,308\,908\,61(30)\times10^{-15}$	m	1.4×10^{-9}
proton rms charge radius	R_p	$0.8768(69)\times10^{-15}$	m	7.8×10^{-3}
proton magnetic moment	μ_p	$1.410\,606\,662(37)\times10^{-26}$	J T^{-1}	2.6×10^{-8}
to Bohr magneton ratio	μ_p/μ_B	$1.521\,032\,209(12)\times10^{-3}$		8.1×10^{-9}
to nuclear magneton ratio	μ_p/μ_N	2.792 847 356(23)		8.2×10^{-9}
proton *g*-factor $2\mu_p/\mu_N$	g_p	5.585 694 713(46)		8.2×10^{-9}
proton-neutron magnetic moment ratio	μ_p/μ_n	−1.459 898 06(34)		2.4×10^{-7}
shielded proton magnetic moment (H_2O, sphere, 25 °C)	μ'_p	$1.410\,570\,419(38)\times10^{-26}$	J T^{-1}	2.7×10^{-8}
to Bohr magneton ratio	μ'_p/μ_B	$1.520\,993\,128(17)\times10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ'_p/μ_N	2.792 775 598(30)		1.1×10^{-8}
proton magnetic shielding correction $1-\mu'_p/\mu_p$ (H_2O, sphere, 25 °C)	σ'_p	$25.694(14)\times10^{-6}$		5.3×10^{-4}
proton gyromagnetic ratio $2\mu_p/\hbar$	γ_p	$2.675\,222\,099(70)\times10^{8}$	s^{-1} T^{-1}	2.6×10^{-8}
	$\gamma_p/2\pi$	42.577 4821(11)	MHz T^{-1}	2.6×10^{-8}
shielded proton gyromagnetic ratio $2\mu'_p/\hbar$ (H_2O, sphere, 25 °C)	γ'_p	$2.675\,153\,362(73)\times10^{8}$	s^{-1} T^{-1}	2.7×10^{-8}
	$\gamma'_p/2\pi$	42.576 3881(12)	MHz T^{-1}	2.7×10^{-8}
		Neutron, n		
neutron mass	m_n	$1.674\,927\,211(84)\times10^{-27}$	kg	5.0×10^{-8}
in u, $m_n = A_r(\mathrm{n})$ u (neutron relative atomic mass times u)		1.008 664 915 97(43)	u	4.3×10^{-10}
energy equivalent	$m_n c^2$	$1.505\,349\,505(75)\times10^{-10}$	J	5.0×10^{-8}
in MeV		939.565 346(23)	MeV	2.5×10^{-8}
neutron-electron mass ratio	m_n/m_e	1838.683 6605(11)		6.0×10^{-10}
neutron-muon mass ratio	m_n/m_μ	8.892 484 09(23)		2.5×10^{-8}
neutron-tau mass ratio	m_n/m_τ	0.528 740(86)		1.6×10^{-4}
neutron-proton mass ratio	m_n/m_p	1.001 378 419 18(46)		4.6×10^{-10}
neutron molar mass $N_A m_n$	$M(\mathrm{n}), M_n$	$1.008\,664\,915\,97(43)\times10^{-3}$	kg mol^{-1}	4.3×10^{-10}
neutron Compton wavelength $h/m_n c$	$\lambda_{C,n}$	$1.319\,590\,8951(20)\times10^{-15}$	m	1.5×10^{-9}
$\lambda_{C,n}/2\pi$	$\lambdabar_{C,n}$	$0.210\,019\,413\,82(31)\times10^{-15}$	m	1.5×10^{-9}
neutron magnetic moment	μ_n	$-0.966\,236\,41(23)\times10^{-26}$	J T^{-1}	2.4×10^{-7}
to Bohr magneton ratio	μ_n/μ_B	$-1.041\,875\,63(25)\times10^{-3}$		2.4×10^{-7}
to nuclear magneton ratio	μ_n/μ_N	−1.913 042 73(45)		2.4×10^{-7}
neutron *g*-factor $2\mu_n/\mu_N$	g_n	−3.826 085 45(90)		2.4×10^{-7}
neutron-electron magnetic moment ratio	μ_n/μ_e	$1.040\,668\,82(25)\times10^{-3}$		2.4×10^{-7}
neutron-proton magnetic moment ratio	μ_n/μ_p	−0.684 979 34(16)		2.4×10^{-7}
neutron to shielded proton magnetic moment ratio (H_2O, sphere, 25 °C)	μ_n/μ'_p	−0.684 996 94(16)		2.4×10^{-7}

TABLE XLIX. (*Continued.*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
neutron gyromagnetic ratio $2\|\mu_n\|/\hbar$	γ_n	$1.832\,471\,85(43)\times10^{8}$	$s^{-1}\,T^{-1}$	2.4×10^{-7}
	$\gamma_n/2\pi$	29.164 6954(69)	MHz T^{-1}	2.4×10^{-7}
Deuteron, d				
deuteron mass	m_d	$3.343\,583\,20(17)\times10^{-27}$	kg	5.0×10^{-8}
in u, $m_d=A_r(d)$ u (deuteron relative atomic mass times u)		2.013 553 212 724(78)	u	3.9×10^{-11}
energy equivalent	m_dc^2	$3.005\,062\,72(15)\times10^{-10}$	J	5.0×10^{-8}
in MeV		1875.612 793(47)	MeV	2.5×10^{-8}
deuteron-electron mass ratio	m_d/m_e	3670.482 9654(16)		4.3×10^{-10}
deuteron-proton mass ratio	m_d/m_p	1.999 007 501 08(22)		1.1×10^{-10}
deuteron molar mass N_Am_d	$M(d), M_d$	$2.013\,553\,212\,724(78)\times10^{-3}$	kg mol^{-1}	3.9×10^{-11}
deuteron rms charge radius	R_d	$2.1402(28)\times10^{-15}$	m	1.3×10^{-3}
deuteron magnetic moment	μ_d	$0.433\,073\,465(11)\times10^{-26}$	J T^{-1}	2.6×10^{-8}
to Bohr magneton ratio	μ_d/μ_B	$0.466\,975\,4556(39)\times10^{-3}$		8.4×10^{-9}
to nuclear magneton ratio	μ_d/μ_N	0.857 438 2308(72)		8.4×10^{-9}
deuteron *g*-factor μ_d/μ_N	g_d	0.857 438 2308(72)		8.4×10^{-9}
deuteron-electon magnetic moment ratio	μ_d/μ_e	$-4.664\,345\,537(39)\times10^{-4}$		8.4×10^{-9}
deuteron-proton magnetic moment ratio	μ_d/μ_p	0.307 012 2070(24)		7.7×10^{-9}
deuteron-neutron magnetic moment ratio	μ_d/μ_n	−0.448 206 52(11)		2.4×10^{-7}
Triton, t				
triton mass	m_t	$5.007\,355\,88(25)\times10^{-27}$	kg	5.0×10^{-8}
in u, $m_t=A_r(t)$ u (triton relative atomic mass times u)		3.015 500 7134(25)	u	8.3×10^{-10}
energy equivalent	m_tc^2	$4.500\,387\,03(22)\times10^{-10}$	J	5.0×10^{-8}
in MeV		2808.920 906(70)	MeV	2.5×10^{-8}
triton-electron mass ratio	m_t/m_e	5496.921 5269(51)		9.3×10^{-10}
triton-proton mass ratio	m_t/m_p	2.993 717 0309(25)		8.4×10^{-10}
triton molar mass N_Am_t	$M(t), M_t$	$3.015\,500\,7134(25)\times10^{-3}$	kg mol^{-1}	8.3×10^{-10}
triton magnetic moment	μ_t	$1.504\,609\,361(42)\times10^{-26}$	J T^{-1}	2.8×10^{-8}
to Bohr magneton ratio	μ_t/μ_B	$1.622\,393\,657(21)\times10^{-3}$		1.3×10^{-8}
to nuclear magneton ratio	μ_t/μ_N	2.978 962 448(38)		1.3×10^{-8}
triton *g*-factor $2\mu_t/\mu_N$	g_t	5.957 924 896(76)		1.3×10^{-8}
triton-electron magnetic moment ratio	μ_t/μ_e	$-1.620\,514\,423(21)\times10^{-3}$		1.3×10^{-8}
triton-proton magnetic moment ratio	μ_t/μ_p	1.066 639 908(10)		9.8×10^{-9}
triton-neutron magnetic moment ratio	μ_t/μ_n	−1.557 185 53(37)		2.4×10^{-7}
Helion, h				
helion (^{3}He nucleus) mass	m_h	$5.006\,411\,92(25)\times10^{-27}$	kg	5.0×10^{-8}
in u, $m_h=A_r(h)$ u (helion relative atomic mass times u)		3.014 932 2473(26)	u	8.6×10^{-10}
energy equivalent	m_hc^2	$4.499\,538\,64(22)\times10^{-10}$	J	5.0×10^{-8}
in MeV		2808.391 383(70)	MeV	2.5×10^{-8}
helion-electron mass ratio	m_h/m_e	5495.885 2765(52)		9.5×10^{-10}

TABLE XLIX. (*Continued.*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
helion-proton mass ratio	m_h/m_p	2.993 152 6713(26)		8.7×10^{-10}
helion molar mass N_Am_h	$M(h), M_h$	$3.014\,932\,2473(26)\times10^{-3}$	kg mol^{-1}	8.6×10^{-10}
shielded helion magnetic moment (gas, sphere, 25 °C)	μ'_h	$-1.074\,552\,982(30)\times10^{-26}$	J T^{-1}	2.8×10^{-8}
to Bohr magneton ratio	μ'_h/μ_B	$-1.158\,671\,471(14)\times10^{-3}$		1.2×10^{-8}
to nuclear magneton ratio	μ'_h/μ_N	−2.127 497 718(25)		1.2×10^{-8}
shielded helion to proton magnetic moment ratio (gas, sphere, 25 °C)	μ'_h/μ_p	−0.761 766 558(11)		1.4×10^{-8}
shielded helion to shielded proton magnetic moment ratio (gas/H_2O, spheres, 25 °C)	μ'_h/μ'_p	−0.761 786 1313(33)		4.3×10^{-9}
shielded helion gyromagnetic ratio $2\lvert\mu'_h\rvert/\hbar$ (gas, sphere, 25 °C)	γ'_h	$2.037\,894\,730(56)\times10^{8}$	s^{-1} T^{-1}	2.8×10^{-8}
	$\gamma'_h/2\pi$	32.434 101 98(90)	MHz T^{-1}	2.8×10^{-8}
Alpha particle, α				
alpha particle mass	m_α	$6.644\,656\,20(33)\times10^{-27}$	kg	5.0×10^{-8}
in u, $m_\alpha=A_r(\alpha)$ u (alpha particle relative atomic mass times u)		4.001 506 179 127(62)	u	1.5×10^{-11}
energy equivalent	$m_\alpha c^2$	$5.971\,919\,17(30)\times10^{-10}$	J	5.0×10^{-8}
in MeV		3727.379 109(93)	MeV	2.5×10^{-8}
α particle to electron mass ratio	m_α/m_e	7294.299 5365(31)		4.2×10^{-10}
α particle to proton mass ratio	m_α/m_p	3.972 599 689 51(41)		1.0×10^{-10}
α particle molar mass N_Am_α	$M(\alpha), M_\alpha$	$4.001\,506\,179\,127(62)\times10^{-3}$	kg mol^{-1}	1.5×10^{-11}
PHYSICOCHEMICAL				
Avogadro constant	N_A, L	$6.022\,141\,79(30)\times10^{23}$	mol^{-1}	5.0×10^{-8}
atomic mass constant $m_u=\frac{1}{12}m(^{12}C)=1$ u $=10^{-3}$ kg mol$^{-1}/N_A$	m_u	$1.660\,538\,782(83)\times10^{-27}$	kg	5.0×10^{-8}
energy equivalent	m_uc^2	$1.492\,417\,830(74)\times10^{-10}$	J	5.0×10^{-8}
in MeV		931.494 028(23)	MeV	2.5×10^{-8}
Faraday constant[f] N_Ae	F	96 485.3399(24)	C mol^{-1}	2.5×10^{-8}
molar Planck constant	N_Ah	$3.990\,312\,6821(57)\times10^{-10}$	J s mol^{-1}	1.4×10^{-9}
	N_Ahc	0.119 626 564 72(17)	J m mol^{-1}	1.4×10^{-9}
molar gas constant	R	8.314 472(15)	J mol^{-1} K^{-1}	1.7×10^{-6}
Boltzmann constant R/N_A	k	$1.380\,6504(24)\times10^{-23}$	J K^{-1}	1.7×10^{-6}
in eV K^{-1}		$8.617\,343(15)\times10^{-5}$	eV K^{-1}	1.7×10^{-6}
	k/h	$2.083\,6644(36)\times10^{10}$	Hz K^{-1}	1.7×10^{-6}
	k/hc	69.503 56(12)	m^{-1} K^{-1}	1.7×10^{-6}
molar volume of ideal gas RT/p $T=273.15$ K, $p=101.325$ kPa	V_m	$22.413\,996(39)\times10^{-3}$	m^3 mol^{-1}	1.7×10^{-6}
Loschmidt constant N_A/V_m	n_0	$2.686\,7774(47)\times10^{25}$	m^{-3}	1.7×10^{-6}
$T=273.15$ K, $p=100$ kPa	V_m	$22.710\,981(40)\times10^{-3}$	m^3 mol^{-1}	1.7×10^{-6}
Sackur-Tetrode constant (absolute entropy constant)[g] $\frac{5}{2}+\ln[(2\pi m_ukT_1/h^2)^{3/2}kT_1/p_0]$				
$T_1=1$ K, $p_0=100$ kPa	S_0/R	−1.151 7047(44)		3.8×10^{-6}
$T_1=1$ K, $p_0=101.325$ kPa		−1.164 8677(44)		3.8×10^{-6}

TABLE XLIX. (*Continued.*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
Stefan-Boltzmann constant $(\pi^2/60)k^4/\hbar^3c^2$	σ	$5.670\,400(40)\times10^{-8}$	W m^{-2} K^{-4}	7.0×10^{-6}
first radiation constant $2\pi hc^2$	c_1	$3.741\,771\,18(19)\times10^{-16}$	W m^2	5.0×10^{-8}
first radiation constant for spectral radiance $2hc^2$	c_{1L}	$1.191\,042\,759(59)\times10^{-16}$	W m^2 sr^{-1}	5.0×10^{-8}
second radiation constant hc/k	c_2	$1.438\,7752(25)\times10^{-2}$	m K	1.7×10^{-6}
Wien displacement law constants				
$b=\lambda_{\max}T=c_2/4.965\,114\,231\ldots$	b	$2.897\,7685(51)\times10^{-3}$	m K	1.7×10^{-6}
$b'=\nu_{\max}/T=2.821\,439\,372\ldots c/c_2$	b'	$5.878\,933(10)\times10^{10}$	Hz K^{-1}	1.7×10^{-6}

[a] See Table LI for the conventional value adopted internationally for realizing representations of the volt using the Josephson effect.

[b] See Table LI for the conventional value adopted internationally for realizing representations of the ohm using the quantum Hall effect.

[c] Value recommended by the Particle Data Group (Yao *et al.*, 2006).

[d] Based on the ratio of the masses of the W and Z bosons m_W/m_Z recommended by the Particle Data Group (Yao *et al.*, 2006). The value for $\sin^2\theta_W$ they recommend, which is based on a particular variant of the modified minimal subtraction scheme ($\overline{\mathrm{MS}}$), is $\sin^2\hat{\theta}_W(M_Z)=0.231\,22(15)$.

[e] This and all other values involving m_τ are based on the value of $m_\tau c^2$ in MeV recommended by the Particle Data Group (Yao *et al.*, 2006), but with a standard uncertainty of 0.29 MeV rather than the quoted uncertainty of −0.26 MeV, +0.29 MeV.

[f] The numerical value of F to be used in coulometric chemical measurements is $96\,485.3401(48)$ $[5.0\times10^{-8}]$ when the relevant current is measured in terms of representations of the volt and ohm based on the Josephson and quantum Hall effects and the internationally adopted conventional values of the Josephson and von Klitzing constants K_{J-90} and R_{K-90} given in Table LI.

[g] The entropy of an ideal monatomic gas of relative atomic mass A_r is given by $S=S_0+\frac{3}{2}R\ln A_r-R\ln(p/p_0)+\frac{5}{2}R\ln(T/K)$.

sponding value expressed in another unit (in essence, an automated version of Tables LIV and LV).

As discussed in Sec. V, well after the 31 December 2006 closing date of the 2006 adjustment and the 29 March 2007 distribution date of the 2006 recommended values on the web, Aoyama *et al.* (2007) reported their discovery of an error in the coefficient $A_1^{(8)}$ in the theoretical expression for the electron magnetic moment anomaly a_e. Use of the new coefficient would lead to an increase in the 2006 recommended value of α by 6.8 times its uncertainty, and an increase of its uncertainty by a factor of 1.02. The recommended values and uncertainties of constants that depend solely on α, or on α in combination with other constants with u_r no larger than a few parts in 10^{10}, would change in the same way. However, the changes in the recommended values of the vast majority of the constants listed in the tables would lie in the range 0 to 0.5 times their 2006 uncertainties, and their uncertainties would remain essentially unchanged.

TABLE L. The variances, covariances, and correlation coefficients of the values of a selected group of constants based on the 2006 CODATA adjustment. The numbers in bold above the main diagonal are 10^{16} times the numerical values of the relative covariances, the numbers in bold on the main diagonal are 10^{16} times the numerical values of the relative variances, and the numbers in italics below the main diagonal are the correlation coefficients.[a]

	α	h	e	m_e	N_A	m_e/m_μ	F
α	**0.0047**	**0.0002**	**0.0024**	**−0.0092**	**0.0092**	**−0.0092**	**0.0116**
h	*0.0005*	**24.8614**	**12.4308**	**24.8611**	**−24.8610**	**−0.0003**	**−12.4302**
e	*0.0142*	*0.9999*	**6.2166**	**12.4259**	**−12.4259**	**−0.0048**	**−6.2093**
m_e	*−0.0269*	*0.9996*	*0.9992*	**24.8795**	**−24.8794**	**0.0180**	**−12.4535**
N_A	*0.0269*	*−0.9996*	*−0.9991*	*−1.0000*	**24.8811**	**−0.0180**	**12.4552**
m_e/m_μ	*−0.0528*	*0.0000*	*−0.0008*	*0.0014*	*−0.0014*	**6.4296**	**−0.0227**
F	*0.0679*	*−0.9975*	*−0.9965*	*−0.9990*	*0.9991*	*−0.0036*	**6.2459**

[a] The relative covariance is $u_r(x_i,x_j)=u(x_i,x_j)/(x_ix_j)$, where $u(x_i,x_j)$ is the covariance of x_i and x_j; the relative variance is $u_r^2(x_i)=u_r(x_i,x_i)$; and the correlation coefficient is $r(x_i,x_j)=u(x_i,x_j)/[u(x_i)u(x_j)]$.

TABLE LI. Internationally adopted values of various quantities.

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
relative atomic mass[a] of ^{12}C	$A_r(^{12}C)$	12		(Exact)
molar mass constant	M_u	1×10^{-3}	kg mol^{-1}	(Exact)
molar mass of ^{12}C	$M(^{12}C)$	12×10^{-3}	kg mol^{-1}	(Exact)
conventional value of Josephson constant[b]	K_{J-90}	483 597.9	GHz V^{-1}	(Exact)
conventional value of von Klitzing constant[c]	R_{K-90}	25 812.807	Ω	(Exact)
standard atmosphere		101 325	Pa	(Exact)

[a] The relative atomic mass $A_r(X)$ of particle X with mass $m(X)$ is $A_r(X)=m(X)/m_u$, where $m_u=m(^{12}C)/12=M_u/N_A=1$ u is the atomic mass constant, M_u is the molar mass constant, N_A is the Avogadro constant, and u is the unified atomic mass unit. Thus the mass of particle X is $m(X)=A_r(X)$ u and the molar mass of X is $M(X)=A_r(X)M_u$.

[b] This is the value adopted internationally for realizing representations of the volt using the Josephson effect.

[c] This is the value adopted internationally for realizing representations of the ohm using the quantum Hall effect.

XIV. SUMMARY AND CONCLUSION

We conclude by (i) comparing the 2006 and 2002 CODATA recommended values of the constants and identifying those new results that have contributed most to the changes from the 2002 values, (ii) presenting some conclusions that can be drawn from the 2006 recommended values and analysis of the 2006 input data, and (iii) looking to the future and identifying experimental and theoretical work that can advance our knowledge of the values of the constants.

A. Comparison of 2006 and 2002 CODATA recommended values

The 2006 and 2002 recommended values of a representative group of constants are compared in Table LVI. Regularities in the numbers in columns 2–4 arise because many constants are obtained from expressions proportional to α, h, or R raised to various powers. Thus, the first six quantities are calculated from expressions proportional to α^a, where $|a|=1$, 2, 3, or 6. The next 15 quantities, h through μ_p, are calculated from expressions containing the factor h^a, where $|a|=1$ or $\frac{1}{2}$. And the five quantities R through σ are proportional to R^a, where $|a|=1$ or 4.

Further comments on the entries in Table LVI are as follows.

(i) The uncertainty of the 2002 recommended value of α has been reduced by nearly a factor of 5 by the measurement of a_e at Harvard University and the improved theoretical expression for a_e(th). The difference between the Harvard result and the earlier University of Washington result, which played a major role in the determination of α in the 2002 adjustment, accounts for most of the change in the recommended value of α from 2002 to 2006.

TABLE LII. Values of some x-ray-related quantities based on the 2006 CODATA adjustment of the values of the constants.

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
Cu x unit: $\lambda(\mathrm{CuK}\alpha_1)/1\,537.400$	$\mathrm{xu}(\mathrm{CuK}\alpha_1)$	$1.002\,076\,99(28)\times10^{-13}$	m	2.8×10^{-7}
Mo x unit: $\lambda(\mathrm{MoK}\alpha_1)/707.831$	$\mathrm{xu}(\mathrm{MoK}\alpha_1)$	$1.002\,099\,55(53)\times10^{-13}$	m	5.3×10^{-7}
ångström star: $\lambda(\mathrm{WK}\alpha_1)/0.209\,010\,0$	Å*	$1.000\,014\,98(90)\times10^{-10}$	m	9.0×10^{-7}
lattice parameter[a] of Si (in vacuum, 22.5 °C)	a	$543.102\,064(14)\times10^{-12}$	m	2.6×10^{-8}
{220} lattice spacing of Si $a/\sqrt{8}$ (in vacuum, 22.5 °C)	d_{220}	$192.015\,5762(50)\times10^{-12}$	m	2.6×10^{-8}
molar volume of Si $M(\mathrm{Si})/\rho(\mathrm{Si})=N_A a^3/8$ (in vacuum, 22.5 °C)	$V_m(\mathrm{Si})$	$12.058\,8349(11)\times10^{-6}$	m^3 mol^{-1}	9.1×10^{-8}

[a] This is the lattice parameter (unit cell edge length) of an ideal single crystal of naturally occurring Si free of impurities and imperfections, and is deduced from measurements on extremely pure and nearly perfect single crystals of Si by correcting for impurity effects.

TABLE LIII. The values in SI units of some non-SI units based on the 2006 CODATA adjustment of the values of the constants.

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
Non-SI units accepted for use with the SI				
electron volt: (e/C) J	eV	$1.602\,176\,487(40)\times10^{-19}$	J	2.5×10^{-8}
(unified) atomic mass unit $1\ \mathrm{u}=m_\mathrm{u}=\frac{1}{12}m(^{12}\mathrm{C})$ $=10^{-3}\ \mathrm{kg\ mol^{-1}}/N_\mathrm{A}$	u	$1.660\,538\,782(83)\times10^{-27}$	kg	5.0×10^{-8}
Natural units (n.u.)				
n.u. of velocity:				
speed of light in vacuum	c, c_0	299 792 458	m s^{-1}	(Exact)
n.u. of action:				
reduced Planck constant $(h/2\pi)$	$\hbar$	$1.054\,571\,628(53)\times10^{-34}$	J s	5.0×10^{-8}
in eV s		$6.582\,118\,99(16)\times10^{-16}$	eV s	2.5×10^{-8}
in MeV fm	$\hbar c$	$197.326\,9631(49)$	MeV fm	2.5×10^{-8}
n.u. of mass:				
electron mass	m_e	$9.109\,382\,15(45)\times10^{-31}$	kg	5.0×10^{-8}
n.u. of energy	$m_\mathrm{e}c^2$	$8.187\,104\,38(41)\times10^{-14}$	J	5.0×10^{-8}
in MeV		$0.510\,998\,910(13)$	MeV	2.5×10^{-8}
n.u. of momentum	$m_\mathrm{e}c$	$2.730\,924\,06(14)\times10^{-22}$	kg m s^{-1}	5.0×10^{-8}
in MeV/c		$0.510\,998\,910(13)$	MeV/c	2.5×10^{-8}
n.u. of length $(\hbar/m_\mathrm{e}c)$	$\bar{\lambda}_\mathrm{C}$	$386.159\,264\,59(53)\times10^{-15}$	m	1.4×10^{-9}
n.u. of time	$\hbar/m_\mathrm{e}c^2$	$1.288\,088\,6570(18)\times10^{-21}$	s	1.4×10^{-9}
Atomic units (a.u.)				
a.u. of charge:				
elementary charge	e	$1.602\,176\,487(40)\times10^{-19}$	C	2.5×10^{-8}
a.u. of mass:				
electron mass	m_e	$9.109\,382\,15(45)\times10^{-31}$	kg	5.0×10^{-8}
a.u. of action:				
reduced Planck constant $(h/2\pi)$	$\hbar$	$1.054\,571\,628(53)\times10^{-34}$	J s	5.0×10^{-8}
a.u. of length:				
Bohr radius (bohr) $(\alpha/4\pi R_\infty)$	a_0	$0.529\,177\,208\,59(36)\times10^{-10}$	m	6.8×10^{-10}
a.u. of energy:				
Hartree energy (hartree) $(e^2/4\pi\epsilon_0 a_0=2R_\infty hc=\alpha^2 m_\mathrm{e}c^2)$	E_h	$4.359\,743\,94(22)\times10^{-18}$	J	5.0×10^{-8}
a.u. of time	$\hbar/E_\mathrm{h}$	$2.418\,884\,326\,505(16)\times10^{-17}$	s	6.6×10^{-12}
a.u. of force	E_h/a_0	$8.238\,722\,06(41)\times10^{-8}$	N	5.0×10^{-8}
a.u. of velocity (αc)	$a_0E_\mathrm{h}/\hbar$	$2.187\,691\,2541(15)\times10^{6}$	m s^{-1}	6.8×10^{-10}
a.u. of momentum	$\hbar/a_0$	$1.992\,851\,565(99)\times10^{-24}$	kg m s^{-1}	5.0×10^{-8}
a.u. of current	$eE_\mathrm{h}/\hbar$	$6.623\,617\,63(17)\times10^{-3}$	A	2.5×10^{-8}
a.u. of charge density	e/a_0^3	$1.081\,202\,300(27)\times10^{12}$	C m^{-3}	2.5×10^{-8}
a.u. of electric potential	E_h/e	$27.211\,383\,86(68)$	V	2.5×10^{-8}
a.u. of electric field	E_h/ea_0	$5.142\,206\,32(13)\times10^{11}$	V m^{-1}	2.5×10^{-8}
a.u. of electric field gradient	E_h/ea_0^2	$9.717\,361\,66(24)\times10^{21}$	V m^{-2}	2.5×10^{-8}
a.u. of electric dipole moment	ea_0	$8.478\,352\,81(21)\times10^{-30}$	C m	2.5×10^{-8}
a.u. of electric quadrupole moment	ea_0^2	$4.486\,551\,07(11)\times10^{-40}$	C m^2	2.5×10^{-8}
a.u. of electric polarizability	$e^2a_0^2/E_\mathrm{h}$	$1.648\,777\,2536(34)\times10^{-41}$	C^2 m^2 J^{-1}	2.1×10^{-9}
a.u. of 1st hyperpolarizability	$e^3a_0^3/E_\mathrm{h}^2$	$3.206\,361\,533(81)\times10^{-53}$	C^3 m^3 J^{-2}	2.5×10^{-8}
a.u. of 2nd hyperpolarizability	$e^4a_0^4/E_\mathrm{h}^3$	$6.235\,380\,95(31)\times10^{-65}$	C^4 m^4 J^{-3}	5.0×10^{-8}
a.u. of magnetic flux density	$\hbar/ea_0^2$	$2.350\,517\,382(59)\times10^{5}$	T	2.5×10^{-8}
a.u. of magnetic dipole moment $(2\mu_\mathrm{B})$	$\hbar e/m_\mathrm{e}$	$1.854\,801\,830(46)\times10^{-23}$	J T^{-1}	2.5×10^{-8}

TABLE LIII. (*Continued.*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
a.u. of magnetizability	$e^2a_0^2/m_e$	$7.891\,036\,433(27)\times 10^{-29}$	J T^{-2}	3.4×10^{-9}
a.u. of permittivity ($10^7/c^2$)	e^2/a_0E_h	$1.112\,650\,056\ldots\times 10^{-10}$	F m^{-1}	(Exact)

(ii) The uncertainty of the 2002 recommended value of h has been reduced by over a factor of 3 due to the new NIST watt-balance result for $K_J^2R_K$ and because the factor used to increase the uncertainties of the data related to h (applied to reduce the inconsistencies among the data) was reduced from 2.325 in the 2002 adjustment to 1.5 in the 2006 adjustment. That the change in value from 2002 to 2006 is small is due to the excellent agreement between the new value of $K_J^2R_K$ and the earlier NIST and NPL values, which played a major role in the determination of h in the 2002 adjustment.

(iii) The updating of two measurements that contributed to the determination of the 2002 recommended value of G reduced the spread in the values and reinforced the most accurate result, that from the University of Washington. On this basis, the Task Group reduced the assigned uncertainty from $u_r=1.5\times 10^{-4}$ in 2002 to $u_r=1.0\times 10^{-4}$ in 2006. This uncertainty reflects the historical difficulty of measuring G. Although the recommended value is the weighted mean of the eight available values, the assigned uncertainty is still over four times the uncertainty of the mean multiplied by the corresponding Birge ratio R_B.

(iv) The large shift in the recommended value of d_{220} from 2002 to 2006 is due to the fact that in the 2002 adjustment only the NMIJ result for d_{220}(NR3) was included, while in the 2006 adjustment this result (but updated by more recent NMIJ measurements) was included together with the PTB result for d_{220}(W4.2a) and the new INRIM results for d_{220}(W4.2a) and d_{220}(MO*). Moreover, the NMIJ value of d_{220} inferred from

TABLE LIV. The values of some energy equivalents derived from $E=mc^2=hc/\lambda=h\nu=kT$, and based on the 2006 CODATA adjustment of the values of the constants; 1 eV$=(e/\mathrm{C})$ J, 1 u$=m_u=\frac{1}{12}m(^{12}\mathrm{C})=10^{-3}$ kg mol$^{-1}/N_A$, and $E_h=2R_\infty hc=\alpha^2m_ec^2$ is the Hartree energy (hartree).

	Relevant unit			
	J	kg	m^{-1}	Hz
1 J	(1 J)= 1 J	(1 J)$/c^2$= $1.112\,650\,056\ldots\times 10^{-17}$ kg	(1 J)$/hc$= $5.034\,117\,47(25)\times 10^{24}$ m^{-1}	(1 J)$/h$= $1.509\,190\,450(75)\times 10^{33}$ Hz
1 kg	(1 kg)c^2= $8.987\,551\,787\ldots\times 10^{16}$ J	(1 kg)= 1 kg	(1 kg)c/h= $4.524\,439\,15(23)\times 10^{41}$ m^{-1}	(1 kg)c^2/h= $1.356\,392\,733(68)\times 10^{50}$ Hz
1 m^{-1}	(1 m^{-1})hc= $1.986\,445\,501(99)\times 10^{-25}$ J	(1 m^{-1})h/c= $2.210\,218\,70(11)\times 10^{-42}$ kg	(1 m^{-1})= 1 m^{-1}	(1 m^{-1})c= 299 792 458 Hz
1 Hz	(1 Hz)h= $6.626\,068\,96(33)\times 10^{-34}$ J	(1 Hz)h/c^2= $7.372\,496\,00(37)\times 10^{-51}$ kg	(1 Hz)$/c$= $3.335\,640\,951\ldots\times 10^{-9}$ m^{-1}	(1 Hz)= 1 Hz
1 K	(1 K)k= $1.380\,6504(24)\times 10^{-23}$ J	(1 K)k/c^2= $1.536\,1807(27)\times 10^{-40}$ kg	(1 K)k/hc= $69.503\,56(12)$ m^{-1}	(1 K)k/h= $2.083\,6644(36)\times 10^{10}$ Hz
1 eV	(1 eV)= $1.602\,176\,487(40)\times 10^{-19}$ J	(1 eV)$/c^2$= $1.782\,661\,758(44)\times 10^{-36}$ kg	(1 eV)$/hc$= $8.065\,544\,65(20)\times 10^{5}$ m^{-1}	(1 eV)$/h$= $2.417\,989\,454(60)\times 10^{14}$ Hz
1 u	(1 u)c^2= $1.492\,417\,830(74)\times 10^{-10}$ J	(1 u)= $1.660\,538\,782(83)\times 10^{-27}$ kg	(1 u)c/h= $7.513\,006\,671(11)\times 10^{14}$ m^{-1}	(1 u)c^2/h= $2.252\,342\,7369(32)\times 10^{23}$ Hz
1 E_h	(1 E_h)= $4.359\,743\,94(22)\times 10^{-18}$ J	(1 E_h)$/c^2$= $4.850\,869\,34(24)\times 10^{-35}$ kg	(1 E_h)$/hc$= $2.194\,746\,313\,705(15)\times 10^{7}$ m^{-1}	(1 E_h)$/h$= $6.579\,683\,920\,722(44)\times 10^{15}$ Hz

TABLE LV. The values of some energy equivalents derived from $E=mc^2=hc/\lambda=h\nu=kT$, and based on the 2006 CODATA adjustment of the values of the constants; 1 eV$=(e/\mathrm{C})$ J, 1 u$=m_\mathrm{u}=\frac{1}{12}m(^{12}\mathrm{C})=10^{-3}$ kg mol$^{-1}/N_\mathrm{A}$, and $E_\mathrm{h}=2R_\infty hc=\alpha^2 m_\mathrm{e}c^2$ is the Hartree energy (hartree).

	Relevant unit			
	K	eV	u	E_h
1 J	$(1\ \mathrm{J})/k=$ $7.242\,963(13)\times10^{22}$ K	$(1\ \mathrm{J})=$ $6.241\,509\,65(16)\times10^{18}$ eV	$(1\ \mathrm{J})/c^2=$ $6.700\,536\,41(33)\times10^{9}$ u	$(1\ \mathrm{J})=$ $2.293\,712\,69(11)\times10^{17}$ E_h
1 kg	$(1\ \mathrm{kg})c^2/k=$ $6.509\,651(11)\times10^{39}$ K	$(1\ \mathrm{kg})c^2=$ $5.609\,589\,12(14)\times10^{35}$ eV	$(1\ \mathrm{kg})=$ $6.022\,141\,79(30)\times10^{26}$ u	$(1\ \mathrm{kg})c^2=$ $2.061\,486\,16(10)\times10^{34}$ E_h
1 m^{-1}	$(1\ \mathrm{m}^{-1})hc/k=$ $1.438\,7752(25)\times10^{-2}$ K	$(1\ \mathrm{m}^{-1})hc=$ $1.239\,841\,875(31)\times10^{-6}$ eV	$(1\ \mathrm{m}^{-1})h/c=$ $1.331\,025\,0394(19)\times10^{-15}$ u	$(1\ \mathrm{m}^{-1})hc=$ $4.556\,335\,252\,760(30)\times10^{-8}$ E_h
1 Hz	$(1\ \mathrm{Hz})h/k=$ $4.799\,2374(84)\times10^{-11}$ K	$(1\ \mathrm{Hz})h=$ $4.135\,667\,33(10)\times10^{-15}$ eV	$(1\ \mathrm{Hz})h/c^2=$ $4.439\,821\,6294(64)\times10^{-24}$ u	$(1\ \mathrm{Hz})h=$ $1.519\,829\,846\,006(10)\times10^{-16}$ E_h
1 K	$(1\ \mathrm{K})=$ 1 K	$(1\ \mathrm{K})k=$ $8.617\,343(15)\times10^{-5}$ eV	$(1\ \mathrm{K})k/c^2=$ $9.251\,098(16)\times10^{-14}$ u	$(1\ \mathrm{K})k=$ $3.166\,8153(55)\times10^{-6}$ E_h
1 eV	$(1\ \mathrm{eV})/k=$ $1.160\,4505(20)\times10^{4}$ K	$(1\ \mathrm{eV})=$ 1 eV	$(1\ \mathrm{eV})/c^2=$ $1.073\,544\,188(27)\times10^{-9}$ u	$(1\ \mathrm{eV})=$ $3.674\,932\,540(92)\times10^{-2}$ E_h
1 u	$(1\ \mathrm{u})c^2/k=$ $1.080\,9527(19)\times10^{13}$ K	$(1\ \mathrm{u})c^2=$ $931.494\,028(23)\times10^{6}$ eV	$(1\ \mathrm{u})=$ 1 u	$(1\ \mathrm{u})c^2=$ $3.423\,177\,7149(49)\times10^{7}$ E_h
1 E_h	$(1\ E_\mathrm{h})/k=$ $3.157\,7465(55)\times10^{5}$ K	$(1\ E_\mathrm{h})=$ $27.211\,383\,86(68)$ eV	$(1\ E_\mathrm{h})/c^2=$ $2.921\,262\,2986(42)\times10^{-8}$ u	$(1\ E_\mathrm{h})=$ 1 E_h

d_{220}(NR3) strongly disagrees with the values of d_{220} inferred from the other three results.

(v) The marginally significant shift in the recommended value of g_μ from 2002 to 2006 is mainly due to the following: In the 2002 adjustment, the principal hadronic contribution to the theoretical expression for a_μ was based on both a calculation that included only $\mathrm{e}^+\mathrm{e}^-$ annihilation data and a calculation that used data from hadronic decays of the τ in place of some of the $\mathrm{e}^+\mathrm{e}^-$ annihilation data. In the 2006 adjustment, the principal hadronic contribution was based on a calculation that used only annihilation data because of various concerns that subsequently arose about the reliability of incorporating the τ data in the calculation; the calculation based on both $\mathrm{e}^+\mathrm{e}^-$ annihilation data and τ decay data was only used to estimate the uncertainty of the hadronic contribution. Because the results from the two calculations are in significant disagreement, the uncertainty of $a_\mu(\mathrm{th})$ is comparatively large: $u_\mathrm{r}=1.8\times10^{-6}$.

(vi) The reduction of the uncertainties of the magnetic moment ratios $\mu_\mathrm{p}/\mu_\mathrm{B}$, $\mu_\mathrm{p}/\mu_\mathrm{N}$, $\mu_\mathrm{d}/\mu_\mathrm{N}$, $\mu_\mathrm{e}/\mu_\mathrm{p}$, and $\mu_\mathrm{d}/\mu_\mathrm{p}$ are due to the new NMR measurement of $\mu_\mathrm{p}(\mathrm{HD})/\mu_\mathrm{d}(\mathrm{HD})$ and careful reexamination of the calculation of the D-H shielding correction difference σ_dp. Because the value of the product $(\mu_\mathrm{p}/\mu_\mathrm{e})(\mu_\mathrm{e}/\mu_\mathrm{d})$ implied by the new measurement is highly consistent with the same product implied by the individual measurements of $\mu_\mathrm{e}(\mathrm{H})/\mu_\mathrm{p}(\mathrm{H})$ and $\mu_\mathrm{d}(\mathrm{D})/\mu_\mathrm{e}(\mathrm{D})$, the changes in the values of the ratios are small.

In summary, the most important differences between the 2006 and 2002 adjustments are that the 2006 adjustment had available new experimental and theoretical results for a_e, which provided a dramatically improved value of α, and a new result for $K_\mathrm{J}^2R_\mathrm{K}$, which provided a significantly improved value of h. These two advances from 2002 to 2006 have resulted in major reductions in the uncertainties of many of the 2006 recommended values compared with their 2002 counterparts.

B. Some implications of the 2006 CODATA recommended values and adjustment for physics and metrology

A number of conclusions that can be drawn from the 2006 adjustment concerning metrology and the basic theories and experimental methods of physics are presented here, where the focus is on those conclusions that are new or are different from those drawn from the 2002 and 1998 adjustments.

Conventional electric units. One can interpret the adoption of the conventional values $K_{\mathrm{J}-90}$