

THE FUNDAMENTAL PHYSICAL CONSTANTS

The 1998 CODATA least-squares adjustment (the most recent carried out) has produced a new set of recommended values of the basic constants and conversion factors of physics and chemistry.

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The Committee on Data for Science and Technology (CODATA) was established in 1966 as an interdisciplinary committee of the International Council of Science (ICSU, formerly the International Council of Scientific Unions). Soon thereafter, in 1969, CODATA established the Task Group on Fundamental Constants (now the Task Group on Fundamental Physical Constants) to periodically provide the scientific and technological communities with a self-consistent set of internationally recommended values of the basic constants and conversion factors of physics and chemistry. Under the auspices of this task group, we have recently completed a new least-squares adjustment of the values of the constants—termed the 1998 adjustment—that takes into account all relevant data available through 31 December 1998.¹ The accompanying tables give the 1998 CODATA recommended values resulting from that adjustment, with the exception of some specialized x-ray-related quantities and various natural and atomic units. The complete 1998 CODATA set of more than 300 recommended values, together with a covariance matrix of some of the more widely used values and a detailed description of the data and their analysis, are given in ref. 1. All of the values and all of their covariances (in the form of correlation coefficients) are available on the Web at <http://physics.nist.gov/constants>, in a searchable database provided by the Fundamental Constants Data Center of the NIST Physics Laboratory.

The 1998 CODATA set of recommended values replaces its immediate predecessor² issued by CODATA in 1986 and is a major step forward. The standard uncertainties (the estimated standard deviations) of many of the 1998 recommended values are about 1/5 to 1/12, and in the case of the Rydberg constant and some associated constants, 1/160 times the standard uncertainties of the corresponding 1986 values. Further, the absolute values of the differences between the 1986 values and the corresponding 1998 values are almost all less than twice the standard uncertainties of the 1986 values. The significant reduction of uncertainties and the relatively small shifts

of values are apparent from the accompanying table, which compares the recommended values of a number of constants from the two adjustments.

The Newtonian constant of gravitation G is unique among the 1998 recommended values; its uncertainty is *larger* than that of the 1986 value by nearly a factor of 12. As explained in detail in ref. 1, for a number of reasons, but especially because of the existence of a value of G from a credible experiment that differs significantly from the 1986 value, the CODATA task group decided to retain the 1986 recommended value but to increase its relative uncertainty from $u_r = 1.3 \times 10^{-4}$ to 1.5×10^{-3} .

The Rydberg constant R_∞ with a shift of 2.7 times its 1986 uncertainty has the largest relative change in value of any constant. However, with a 1986 to 1998 uncertainty ratio of nearly 160, R_∞ has undergone the largest reduction in uncertainty of any constant. The large shift in value occurred because the 1986 recommended value of R_∞ is based mainly on a 1981 experimental result that turned out to be in error. The large uncertainty reduction is mainly due to the fact that, beginning in the early 1990s, optical frequency metrology replaced optical wavelength metrology in the measurement of transition frequencies in hydrogenic atoms, thereby significantly reducing the uncertainties of such measurements. Improvements in the theory of the energy levels of hydrogenic atoms also contributed to the uncertainty reduction.

The following experimental and theoretical advances made during the 13-year period between the 1986 and 1998 adjustments contributed to the reduction of the uncertainties for the fine-structure constant α , Planck constant h , and molar gas constant R . These constants are not only important in their own right, but, together with R_∞ and the relative atomic mass of the electron $A_r(e)$, they determine the recommended values of many other constants and conversion factors of prime interest.

▷ An improved experimental determination of the anomalous magnetic moment of the electron a_e obtained from measurements on a single electron confined in a Penning trap, combined with an improved theoretical expression for a_e calculated from quantum electrodynamics (QED), provides a value of α with $u_r = 3.8 \times 10^{-9}$. The 1998 recommended value of α with $u_r = 3.7 \times 10^{-9}$ is determined mainly by this result.

▷ The moving-coil watt balance, conceived in 1975 and first brought to a useful operational state in the late 1980s, provides two experimental values of $K_J R_K = 4/h$,

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Comparison of the 1998 and 1986 CODATA recommended values of various constants

Quantity	1998 rel. std. uncert. u_r	1986 rel. std. uncert. u_r	Ratio 1986 u_r to 1998 u_r	D_r
α	3.7×10^{-9}	4.5×10^{-8}	12.2	-1.7
λ_C	7.3×10^{-9}	8.9×10^{-8}	12.2	-1.7
h	7.8×10^{-8}	6.0×10^{-7}	7.7	-1.7
N_A	7.9×10^{-8}	5.9×10^{-7}	7.5	1.5
e	3.9×10^{-8}	3.0×10^{-7}	7.8	-1.8
R	1.7×10^{-6}	8.4×10^{-6}	4.8	-0.5
k	1.7×10^{-6}	8.5×10^{-6}	4.8	-0.6
σ	7.0×10^{-6}	3.4×10^{-5}	4.8	-0.6
G	1.5×10^{-3}	1.3×10^{-4}	0.1	0.0
R_∞	7.6×10^{-12}	1.2×10^{-9}	157.1	2.7
m_e/m_p	2.1×10^{-9}	2.0×10^{-8}	9.5	0.9
$A_r(e)$	2.1×10^{-9}	2.3×10^{-8}	11.1	0.7

Note: The relative standard uncertainty of a quantity y is defined as $u_r(y) \equiv u(y)/|y|$, if $y \neq 0$, where $u(y)$ is the standard uncertainty of y . D_r is the 1998 value minus the 1986 value divided by the standard uncertainty of the 1986 value. The various constants are defined in subsequent tables.

one with $u_r = 8.7 \times 10^{-8}$ and the other with $u_r = 2.0 \times 10^{-7}$ ($K_J = 2e/h$ is the Josephson constant, characteristic of the Josephson effect, and $R_K = h/e^2$ is the von Klitzing constant, characteristic of the quantum Hall effect). The 1998 recommended value of h with $u_r = 7.8 \times 10^{-8}$ arises primarily from these two results.

▷ A determination of the speed of sound in argon using a spherical acoustic resonator provides an experimental value of R with $u_r = 1.8 \times 10^{-6}$, about 1/5 times the uncertainty of the 1986 recommended value, which is based on a result obtained using a cylindrical acoustic interferometer. The new value is mainly responsible for the 1998 recommended value of R with $u_r = 1.7 \times 10^{-6}$.

Improved measurements and calculations of a number of other quantities also contributed to our better overall knowledge of the constants. Notable are the Penning-trap mass-ratio measurements that furnished more accurate values of the relative atomic masses of the electron, proton, deuteron, helion (nucleus of ^3He), and α particle; the crystal diffraction determination of the binding energy of the neutron in the deuteron that led to a more accurate value of the relative atomic mass of the neutron; and the Zeeman transition-frequency determination of the ground-state hyperfine splitting in muonium (μ^+e^- atom) $\Delta\nu_{\text{Mu}}$, together with a more accurate theoretical expression for $\Delta\nu_{\text{Mu}}$ calculated from QED, that led to a more accurate value of the electron–muon mass ratio m_e/m_μ .

The 1998 adjustment differs from its 1986 predecessor in several important respects. First, we abandoned the 1986 grouping of the input data into the two distinct categories, stochastic input data and auxiliary constants, where the latter were assumed to be exactly known. Instead, we treated all input data on an essentially equal footing, regardless of their uncertainties. This allowed all components of uncertainty and all correlations among the data to be properly taken into account, while at the same time it eliminated an arbitrary division of the data into two categories.

Second, we did not attempt to quantify the “uncertainty” of the uncertainty assigned each input datum as was done in 1986 in order to analyze the data using

extended least-squares algorithms. The change was made after reviewing in detail literally hundreds of experimental and theoretical results and concluding that, because of the complexity of the measurements and calculations in the field of fundamental constants, it is difficult enough to evaluate their uncertainties in a meaningful way, let alone the “uncertainties” of those uncertainties. We therefore used the standard least-squares algorithm in our data analysis.

Third, in order to properly take into account the uncertainties of various theoretical expressions—for example, those for the energy levels of hydrogen (H) and deuterium (D) required to obtain R_∞ from measurements of transition frequencies in these atoms—we introduced in the 1998 adjustment an additive correction δ_i for each such expression. The δ 's are included among the variables of the least-squares adjustment, and their estimated values are taken as input data. The best *a priori* estimate of each δ_i is assumed to be zero but with a standard uncertainty equal to the standard uncertainty of the theoretical expression. This approach enabled us to account for the uncertainties in the theory in a rigorous way, although it increased the number of variables that we had to deal with and the size of the matrices that we had to invert. Fortunately, modern computers have little difficulty with such inversions.

Fourth, we analyzed the data using the method of least squares for correlated input data. This means that the covariance matrix of the input data was not diagonal. Although the need to consider correlations among the input data in the evaluation of the fundamental constants was first emphasized half a century ago, the 1998 adjustment was the first time it was actually done.

Our analysis of the input data proceeded in multiple stages. First, we compared the various measured values of each quantity. Next, we compared measured values of different quantities by comparing values of a common inferred constant. Prominent among those inferred constants are R_∞ , α , and h . Finally, we carried out a multivariate analysis of the data using the method of least squares as discussed above. Because the input data related to R_∞ are not strongly tied to the rest of the input data, various stages of the analysis were done independently on those two groups of data before the data were combined for final analysis. The focus of all of these investigations was the compatibility of the data and the extent to which a particular datum would contribute to the determination of the 1998 recommended values of the constants.

The final least-squares adjustment on which the 1998 recommended values are based used 93 of the 107 input data that were initially considered and 57 variables or adjusted constants. The 93 input data included values of 9 silicon lattice-spacing differences and 27 H and D transition frequencies and frequency differences. The 57 adjusted constants included 28 δ 's, 8 {220} silicon lattice spacings, R_∞ , α , h , R , $A_r(e)$, and the relative atomic masses of five other particles. Although a number of the 1998 recommended values are adjusted constants and hence were directly determined in the adjustment, most recommended values were subsequently calculated from the adjusted constants. For example, the elementary charge

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CODATA Recommended Values of the Fundamental Physical Constants – 1998

Quantity	Symbol	Value	Unit	Relative standard uncertainty u_r
UNIVERSAL				
speed of light in vacuum	c, c_0	299 792 458	m s ⁻¹	(exact)
magnetic constant	μ_0	$4\pi \times 10^{-7}$ $= 12.566\,370\,614 \dots \times 10^{-7}$	N A ⁻² N A ⁻²	(exact)
electric constant $1/\mu_0 c^2$	ϵ_0	$8.854\,187\,817 \dots \times 10^{-12}$	F m ⁻¹	(exact)
characteristic impedance of vacuum $\sqrt{\mu_0/\epsilon_0} = \mu_0 c$	Z_0	376.730 313 461. . .	Ω	(exact)
Newtonian constant of gravitation	G	$6.673(10) \times 10^{-11}$	m ³ kg ⁻¹ s ⁻²	1.5×10^{-3}
	$G/\hbar c$	$6.707(10) \times 10^{-39}$	(GeV/c ²) ⁻²	1.5×10^{-3}
Planck constant	h	$6.626\,068\,76(52) \times 10^{-34}$	J s	7.8×10^{-8}
in eV s		$4.135\,667\,27(16) \times 10^{-15}$	eV s	3.9×10^{-8}
$\hbar/2\pi$	$\hbar$	$1.054\,571\,596(82) \times 10^{-34}$	J s	7.8×10^{-8}
in eV s		$6.582\,118\,89(26) \times 10^{-16}$	eV s	3.9×10^{-8}
Planck mass $(\hbar c/G)^{1/2}$	m_P	$2.1767(16) \times 10^{-8}$	kg	7.5×10^{-4}
Planck length $\hbar/m_P c = (\hbar G/c^3)^{1/2}$	l_P	$1.6160(12) \times 10^{-35}$	m	7.5×10^{-4}
Planck time $l_P/c = (\hbar G/c^5)^{1/2}$	t_P	$5.3906(40) \times 10^{-44}$	s	7.5×10^{-4}
ELECTROMAGNETIC				
elementary charge	e	$1.602\,176\,462(63) \times 10^{-19}$	C	3.9×10^{-8}
	e/h	$2.417\,989\,491(95) \times 10^{14}$	A J ⁻¹	3.9×10^{-8}
magnetic flux quantum $h/2e$	Φ_0	$2.067\,833\,636(81) \times 10^{-15}$	Wb	3.9×10^{-8}
conductance quantum $2e^2/h$	G_0	$7.748\,091\,696(28) \times 10^{-5}$	S	3.7×10^{-9}
inverse of conductance quantum	G_0^{-1}	$12\,906.403\,786(47)$	Ω	3.7×10^{-9}
Josephson constant ^a $2e/h$	K_J	$483\,597.898(19) \times 10^9$	Hz V ⁻¹	3.9×10^{-8}
von Klitzing constant ^b $h/e^2 = \mu_0 c/2\alpha$	R_K	$25\,812.807\,572(95)$	Ω	3.7×10^{-9}
Bohr magneton $e\hbar/2m_e$	μ_B	$927.400\,899(37) \times 10^{-26}$	J T ⁻¹	4.0×10^{-8}
in eV T ⁻¹		$5.788\,381\,749(43) \times 10^{-5}$	eV T ⁻¹	7.3×10^{-9}
	μ_B/h	$13.996\,246\,24(56) \times 10^9$	Hz T ⁻¹	4.0×10^{-8}
	μ_B/hc	$46.686\,4521(19)$	m ⁻¹ T ⁻¹	4.0×10^{-8}
	μ_B/k	$0.671\,7131(12)$	K T ⁻¹	1.7×10^{-6}
nuclear magneton $e\hbar/2m_p$	μ_N	$5.050\,783\,17(20) \times 10^{-27}$	J T ⁻¹	4.0×10^{-8}
in eV T ⁻¹		$3.152\,451\,238(24) \times 10^{-8}$	eV T ⁻¹	7.6×10^{-9}
	μ_N/h	$7.622\,593\,96(31)$	MHz T ⁻¹	4.0×10^{-8}
	μ_N/hc	$2.542\,623\,66(10) \times 10^{-2}$	m ⁻¹ T ⁻¹	4.0×10^{-8}
	μ_N/k	$3.658\,2638(64) \times 10^{-4}$	K T ⁻¹	1.7×10^{-6}
ATOMIC AND NUCLEAR				
General				
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,533(27) \times 10^{-3}$		3.7×10^{-9}
inverse fine-structure constant	α^{-1}	$137.035\,999\,76(50)$		3.7×10^{-9}
Rydberg constant $\alpha^2 m_e c/2\hbar$	R_∞	$10\,973\,731.568\,549(83)$	m ⁻¹	7.6×10^{-12}
	$R_\infty c$	$3.289\,841\,960\,368(25) \times 10^{15}$	Hz	7.6×10^{-12}
	$R_\infty \hbar c$	$2.179\,871\,90(17) \times 10^{-18}$	J	7.8×10^{-8}
$R_\infty \hbar c$ in eV		$13.605\,691\,72(53)$	eV	3.9×10^{-8}
Bohr radius $\alpha/4\pi R_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2$	a_0	$0.529\,177\,2083(19) \times 10^{-10}$	m	3.7×10^{-9}
Hartree energy $e^2/4\pi\epsilon_0 a_0 = 2R_\infty \hbar c = \alpha^2 m_e c^2$	E_h	$4.359\,743\,81(34) \times 10^{-18}$	J	7.8×10^{-8}
in eV		$27.211\,3834(11)$	eV	3.9×10^{-8}
quantum of circulation	$h/2m_e$	$3.636\,947\,516(27) \times 10^{-4}$	m ² s ⁻¹	7.3×10^{-9}
	h/m_e	$7.273\,895\,032(53) \times 10^{-4}$	m ² s ⁻¹	7.3×10^{-9}
Electroweak				
Fermi coupling constant ^c	$G_F/(\hbar c)^3$	$1.166\,39(1) \times 10^{-5}$	GeV ⁻²	8.6×10^{-6}
weak mixing angle ^d θ_W (on-shell scheme)				
$\sin^2 \theta_W = s_W^2 \equiv 1 - (m_W/m_Z)^2$	$\sin^2 \theta_W$	$0.2224(19)$		8.7×10^{-3}
Electron, e ⁻				
electron mass	m_e	$9.109\,381\,88(72) \times 10^{-31}$	kg	7.9×10^{-8}
in u, $m_e = A_1(e)$ u (electron rel. atomic mass times u)		$5.485\,799\,110(12) \times 10^{-4}$	u	2.1×10^{-9}
energy equivalent	$m_e c^2$	$8.187\,104\,14(64) \times 10^{-14}$	J	7.9×10^{-8}
in MeV		$0.510\,998\,902(21)$	MeV	4.0×10^{-8}
electron–muon mass ratio	m_e/m_μ	$4.836\,332\,10(15) \times 10^{-3}$		3.0×10^{-8}
electron–tau mass ratio	m_e/m_τ	$2.875\,55(47) \times 10^{-4}$		1.6×10^{-4}
electron–proton mass ratio	m_e/m_p	$5.446\,170\,232(12) \times 10^{-4}$		2.1×10^{-9}
electron–neutron mass ratio	m_e/m_n	$5.438\,673\,462(12) \times 10^{-4}$		2.2×10^{-9}
electron–deuteron mass ratio	m_e/m_d	$2.724\,437\,1170(58) \times 10^{-4}$		2.1×10^{-9}
electron to alpha particle mass ratio	m_e/m_α	$1.370\,933\,5611(29) \times 10^{-4}$		2.1×10^{-9}
electron charge to mass quotient	$-e/m_e$	$-1.758\,820\,174(71) \times 10^{11}$	C kg ⁻¹	4.0×10^{-8}
electron molar mass $N_A m_e$	$M(e), M_e$	$5.485\,799\,110(12) \times 10^{-7}$	kg mol ⁻¹	2.1×10^{-9}

CODATA Recommended Values of the Fundamental Physical Constants – 1998

Quantity	Symbol	Value	Unit	Relative standard uncertainty u_r
Compton wavelength $h/m_e c$	λ_C	$2.426\,310\,215(18)\times 10^{-12}$	m	7.3×10^{-9}
$\lambda_C/2\pi=\alpha a_0=\alpha^2/4\pi R_\infty$	$\tilde{\lambda}_C$	$386.159\,2642(28)\times 10^{-15}$	m	7.3×10^{-9}
classical electron radius $\alpha^2 a_0$	r_e	$2.817\,940\,285(31)\times 10^{-15}$	m	1.1×10^{-8}
Thomson cross section $(8\pi/3)r_e^2$	σ_e	$0.665\,245\,854(15)\times 10^{-28}$	m ²	2.2×10^{-8}
electron magnetic moment	μ_e	$-928.476\,362(37)\times 10^{-26}$	J T ⁻¹	4.0×10^{-8}
to Bohr magneton ratio	μ_e/μ_B	$-1.001\,159\,652\,1869(41)$		4.1×10^{-12}
to nuclear magneton ratio	μ_e/μ_N	$-1\,838.281\,9660(39)$		2.1×10^{-9}
electron magnetic moment anomaly $ \mu_e /\mu_B-1$	a_e	$1.159\,652\,1869(41)\times 10^{-3}$		3.5×10^{-9}
electron g-factor $-2(1+a_e)$	g_e	$-2.002\,319\,304\,3737(82)$		4.1×10^{-12}
electron–muon magnetic moment ratio	μ_e/μ_μ	$206.766\,9720(63)$		3.0×10^{-8}
electron–proton magnetic moment ratio	μ_e/μ_p	$-658.210\,6875(66)$		1.0×10^{-8}
electron to shielded proton magnetic moment ratio (H ₂ O, sphere, 25 °C)	μ_e/μ'_p	$-658.227\,5954(71)$		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	$-2\,143.923\,498(23)$		1.1×10^{-8}
electron to shielded helion ^e magnetic moment ratio (gas, sphere, 25 °C)	μ_e/μ'_h	$864.058\,255(10)$		1.2×10^{-8}
electron gyromagnetic ratio $2 \mu_e /\hbar$	γ_e	$1.760\,859\,794(71)\times 10^{11}$	s ⁻¹ T ⁻¹	4.0×10^{-8}
	$\gamma_e/2\pi$	$28\,024.9540(11)$	MHz T ⁻¹	4.0×10^{-8}
Muon, μ^-				
muon mass	m_μ	$1.883\,531\,09(16)\times 10^{-28}$	kg	8.4×10^{-8}
in u, $m_\mu=A_r(\mu)$ u (muon rel. atomic mass times u)		$0.113\,428\,9168(34)$	u	3.0×10^{-8}
energy equivalent	$m_\mu c^2$	$1.692\,833\,32(14)\times 10^{-11}$	J	8.4×10^{-8}
in MeV		$105.658\,3568(52)$	MeV	4.9×10^{-8}
muon–electron mass ratio	m_μ/m_e	$206.768\,2657(63)$		3.0×10^{-8}
muon–tau mass ratio	m_μ/m_τ	$5.945\,72(97)\times 10^{-2}$		1.6×10^{-4}
muon–proton mass ratio	m_μ/m_p	$0.112\,609\,5173(34)$		3.0×10^{-8}
muon–neutron mass ratio	m_μ/m_n	$0.112\,454\,5079(34)$		3.0×10^{-8}
muon molar mass $N_A m_\mu$	$M(\mu), M_\mu$	$0.113\,428\,9168(34)\times 10^{-3}$	kg mol ⁻¹	3.0×10^{-8}
muon Compton wavelength $h/m_\mu c$	$\lambda_{C,\mu}$	$11.734\,441\,97(35)\times 10^{-15}$	m	2.9×10^{-8}
$\lambda_{C,\mu}/2\pi$	$\tilde{\lambda}_{C,\mu}$	$1.867\,594\,444(55)\times 10^{-15}$	m	2.9×10^{-8}
muon magnetic moment	μ_μ	$-4.490\,448\,13(22)\times 10^{-26}$	J T ⁻¹	4.9×10^{-8}
to Bohr magneton ratio	μ_μ/μ_B	$-4.841\,970\,85(15)\times 10^{-3}$		3.0×10^{-8}
to nuclear magneton ratio	μ_μ/μ_N	$-8.890\,597\,70(27)$		3.0×10^{-8}
muon magnetic moment anomaly $ \mu_\mu /(e\hbar/2m_\mu)-1$	a_μ	$1.165\,916\,02(64)\times 10^{-3}$		5.5×10^{-7}
muon g-factor $-2(1+a_\mu)$	g_μ	$-2.002\,331\,8320(13)$		6.4×10^{-10}
muon–proton magnetic moment ratio	μ_μ/μ_p	$-3.183\,345\,39(10)$		3.2×10^{-8}
Tau, τ^-				
tau mass ^f	m_τ	$3.167\,88(52)\times 10^{-27}$	kg	1.6×10^{-4}
in u, $m_\tau=A_r(\tau)$ u (tau rel. atomic mass times u)		$1.907\,74(31)$	u	1.6×10^{-4}
energy equivalent	$m_\tau c^2$	$2.847\,15(46)\times 10^{-10}$	J	1.6×10^{-4}
in MeV		$1\,777.05(29)$	MeV	1.6×10^{-4}
tau–electron mass ratio	m_τ/m_e	$3\,477.60(57)$		1.6×10^{-4}
tau–muon mass ratio	m_τ/m_μ	$16.8188(27)$		1.6×10^{-4}
tau–proton mass ratio	m_τ/m_p	$1.893\,96(31)$		1.6×10^{-4}
tau–neutron mass ratio	m_τ/m_n	$1.891\,35(31)$		1.6×10^{-4}
tau molar mass $N_A m_\tau$	$M(\tau), M_\tau$	$1.907\,74(31)\times 10^{-3}$	kg mol ⁻¹	1.6×10^{-4}
tau Compton wavelength $h/m_\tau c$	$\lambda_{C,\tau}$	$0.697\,70(11)\times 10^{-15}$	m	1.6×10^{-4}
$\lambda_{C,\tau}/2\pi$	$\tilde{\lambda}_{C,\tau}$	$0.111\,042(18)\times 10^{-15}$	m	1.6×10^{-4}
Proton, p				
proton mass	m_p	$1.672\,621\,58(13)\times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_p=A_r(p)$ u (proton rel. atomic mass times u)		$1.007\,276\,466\,88(13)$	u	1.3×10^{-10}
energy equivalent	$m_p c^2$	$1.503\,277\,31(12)\times 10^{-10}$	J	7.9×10^{-8}
in MeV		$938.271\,998(38)$	MeV	4.0×10^{-8}
proton–electron mass ratio	m_p/m_e	$1\,836.152\,6675(39)$		2.1×10^{-9}
proton–muon mass ratio	m_p/m_μ	$8.880\,244\,08(27)$		3.0×10^{-8}
proton–tau mass ratio	m_p/m_τ	$0.527\,994(86)$		1.6×10^{-4}
proton–neutron mass ratio	m_p/m_n	$0.998\,623\,478\,55(58)$		5.8×10^{-10}
proton charge to mass quotient	e/m_p	$9.578\,834\,08(38)\times 10^7$	C kg ⁻¹	4.0×10^{-8}
proton molar mass $N_A m_p$	$M(p), M_p$	$1.007\,276\,466\,88(13)\times 10^{-3}$	kg mol ⁻¹	1.3×10^{-10}
proton Compton wavelength $h/m_p c$	$\lambda_{C,p}$	$1.321\,409\,847(10)\times 10^{-15}$	m	7.6×10^{-9}
$\lambda_{C,p}/2\pi$	$\tilde{\lambda}_{C,p}$	$0.210\,308\,9089(16)\times 10^{-15}$	m	7.6×10^{-9}

CODATA Recommended Values of the Fundamental Physical Constants – 1998

Quantity	Symbol	Value	Unit	Relative standard uncertainty u_r
proton magnetic moment	μ_p	$1.410\,606\,633(58) \times 10^{-26}$	J T ⁻¹	4.1×10^{-8}
to Bohr magneton ratio	μ_p/μ_B	$1.521\,032\,203(15) \times 10^{-3}$		1.0×10^{-8}
to nuclear magneton ratio	μ_p/μ_N	2.792 847 337(29)		1.0×10^{-8}
proton g -factor $2\mu_p/\mu_N$	g_p	5.585 694 675(57)		1.0×10^{-8}
proton-neutron magnetic moment ratio	μ_p/μ_n	-1.459 898 05(34)		2.4×10^{-7}
shielded proton magnetic moment (H ₂ O, sphere, 25 °C)	μ'_p	$1.410\,570\,399(59) \times 10^{-26}$	J T ⁻¹	4.2×10^{-8}
to Bohr magneton ratio	μ'_p/μ_B	$1.520\,993\,132(16) \times 10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ'_p/μ_N	2.792 775 597(31)		1.1×10^{-8}
proton magnetic shielding correction $1 - \mu'_p/\mu_p$ (H ₂ O, sphere, 25 °C)	σ'_p	$25.687(15) \times 10^{-6}$		5.7×10^{-4}
proton gyromagnetic ratio $2\mu_p/\hbar$	γ_p	$2.675\,222\,12(11) \times 10^8$	s ⁻¹ T ⁻¹	4.1×10^{-8}
	$\gamma_p/2\pi$	42.577 4825(18)	MHz T ⁻¹	4.1×10^{-8}
shielded proton gyromagnetic ratio $2\mu'_p/\hbar$ (H ₂ O, sphere, 25 °C)	γ'_p	$2.675\,153\,41(11) \times 10^8$	s ⁻¹ T ⁻¹	4.2×10^{-8}
	$\gamma'_p/2\pi$	42.576 3888(18)	MHz T ⁻¹	4.2×10^{-8}
Neutron, n				
neutron mass	m_n	$1.674\,927\,16(13) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_n = A_r(n)$ u (neutron rel. atomic mass times u)		1.008 664 915 78(55)	u	5.4×10^{-10}
energy equivalent	$m_n c^2$	$1.505\,349\,46(12) \times 10^{10}$	J	7.9×10^{-8}
in MeV		939.565 330(38)	MeV	4.0×10^{-8}
neutron-electron mass ratio	m_n/m_e	1 838.683 6550(40)		2.2×10^{-9}
neutron-muon mass ratio	m_n/m_μ	8.892 484 78(27)		3.0×10^{-8}
neutron-tau mass ratio	m_n/m_τ	0.528 722(86)		1.6×10^{-4}
neutron-proton mass ratio	m_n/m_p	1.001 378 418 87(58)		5.8×10^{-10}
neutron molar mass $N_A m_n$	$M(n), M_n$	$1.008\,664\,915\,78(55) \times 10^{-3}$	kg mol ⁻¹	5.4×10^{-10}
neutron Compton wavelengths $h/m_n c$	$\lambda_{C,n}$	$1.319\,590\,898(10) \times 10^{-15}$	m	7.6×10^{-9}
	$\lambda_{C,n}/2\pi$	$0.210\,019\,4142(16) \times 10^{-15}$	m	7.6×10^{-9}
neutron magnetic moment	μ_n	$-0.966\,236\,40(23) \times 10^{-26}$	J T ⁻¹	2.4×10^{-7}
to Bohr magneton ratio	μ_n/μ_B	$-1.041\,875\,63(25) \times 10^{-3}$		2.4×10^{-7}
to nuclear magneton ratio	μ_n/μ_N	-1.913 042 72(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	$1.040\,668\,82(25) \times 10^{-3}$		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 ₂ O, sphere, 25 °C)	μ_n/μ'_p	-0.684 996 94(16)		2.4×10^{-7}
neutron gyromagnetic ratio $2 \mu_n /\hbar$	γ_n	$1.832\,471\,88(44) \times 10^8$	s ⁻¹ T ⁻¹	2.4×10^{-7}
	$\gamma_n/2\pi$	29.164 6958(70)	MHz T ⁻¹	2.4×10^{-7}
Deuteron, d				
deuteron mass	m_d	$3.343\,583\,09(26) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_d = A_r(d)$ u (deuteron rel. atomic mass times u)		2.013 553 212 71(35)	u	1.7×10^{-10}
energy equivalent	$m_d c^2$	$3.005\,062\,62(24) \times 10^{10}$	J	7.9×10^{-8}
in MeV		1 875.612 762(75)	MeV	4.0×10^{-8}
deuteron-electron mass ratio	m_d/m_e	3 670.482 9550(78)		2.1×10^{-9}
deuteron-proton mass ratio	m_d/m_p	1.999 007 500 83(41)		2.0×10^{-10}
deuteron molar mass $N_A m_d$	$M(d), M_d$	$2.013\,553\,212\,71(35) \times 10^{-3}$	kg mol ⁻¹	1.7×10^{-10}
deuteron magnetic moment	μ_d	$0.433\,073\,457(18) \times 10^{-26}$	J T ⁻¹	4.2×10^{-8}
to Bohr magneton ratio	μ_d/μ_B	$0.466\,975\,4556(50) \times 10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ_d/μ_N	0.857 438 2284(94)		1.1×10^{-8}
deuteron-electron magnetic moment ratio	μ_d/μ_e	$-4.664\,345\,537(50) \times 10^{-4}$		1.1×10^{-8}
deuteron-proton magnetic moment ratio	μ_d/μ_p	0.307 012 2083(45)		1.5×10^{-8}
deuteron-neutron magnetic moment ratio	μ_d/μ_n	-0.448 206 52(11)		2.4×10^{-7}
Helion, h				
helion mass ^e	m_h	$5.006\,411\,74(39) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_h = A_r(h)$ u (helion rel. atomic mass times u)		3.014 932 234 69(86)	u	2.8×10^{-10}
energy equivalent	$m_h c^2$	$4.499\,538\,48(35) \times 10^{10}$	J	7.9×10^{-8}
in MeV		2 808.391 32(11)	MeV	4.0×10^{-8}
helion-electron mass ratio	m_h/m_e	5 495.885 238(12)		2.1×10^{-9}
helion-proton mass ratio	m_h/m_p	2.993 152 658 50(93)		3.1×10^{-10}
helion molar mass $N_A m_h$	$M(h), M_h$	$3.014\,932\,234\,69(86) \times 10^{-3}$	kg mol ⁻¹	2.8×10^{-10}
shielded helion magnetic moment (gas, sphere, 25 °C)	μ'_h	$-1.074\,552\,967(45) \times 10^{-26}$	J T ⁻¹	4.2×10^{-8}
to Bohr magneton ratio	μ'_h/μ_B	$-1.158\,671\,474(14) \times 10^{-3}$		1.2×10^{-8}

CODATA Recommended Values of the Fundamental Physical Constants – 1998

Quantity	Symbol	Value	Unit	Relative standard uncertainty u_r
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	-0.761 766 563(12)		1.5×10^{-8}
shielded helion to shielded proton magnetic moment ratio (gas/H ₂ O, spheres, 25 °C)	μ'_h/μ'_p	-0.761 786 1313(33)		4.3×10^{-9}
shielded helion gyromagnetic ratio $2 \mu'_h /\hbar$ (gas, sphere, 25 °C)	γ'_h	$2.037\,894\,764(85)\times 10^8$	s ⁻¹ T ⁻¹	4.2×10^{-8}
	$\gamma'_h/2\pi$	32.434 1025(14)	MHz T ⁻¹	4.2×10^{-8}
Alpha particle, α				
alpha particle mass	m_α	$6.644\,655\,98(52)\times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_\alpha=A_r(\alpha)$ u (alpha particle rel. atomic mass times u)		4.001 506 1747(10)	u	2.5×10^{-10}
energy equivalent	$m_\alpha c^2$	$5.971\,918\,97(47)\times 10^{-10}$	J	7.9×10^{-8}
in MeV		3 727.379 04(15)	MeV	4.0×10^{-8}
alpha particle to electron mass ratio	m_α/m_e	7 294.299 508(16)		2.1×10^{-9}
alpha particle to proton mass ratio	m_α/m_p	3.972 599 6846(11)		2.8×10^{-10}
alpha particle molar mass $N_A m_\alpha$	$M(\alpha), M_\alpha$	$4.001\,506\,1747(10)\times 10^{-3}$	kg mol ⁻¹	2.5×10^{-10}
PHYSICOCHEMICAL				
Avogadro constant	N_A, L	$6.022\,141\,99(47)\times 10^{23}$	mol ⁻¹	7.9×10^{-8}
atomic mass constant				
$m_u = \frac{1}{12} m(^{12}\text{C}) = 1\text{ u} = 10^{-3}\text{ kg mol}^{-1}/N_A$	m_u	$1.660\,538\,73(13)\times 10^{-27}$	kg	7.9×10^{-8}
energy equivalent	$m_u c^2$	$1.492\,417\,78(12)\times 10^{-10}$	J	7.9×10^{-8}
in MeV		931.494 013(37)	MeV	4.0×10^{-8}
Faraday constant ^g $N_A e$	F	96 485.3415(39)	C mol ⁻¹	4.0×10^{-8}
molar Planck constant	$N_A h$	$3.990\,312\,689(30)\times 10^{-10}$	J s mol ⁻¹	7.6×10^{-9}
	$N_A h c$	0.119 626 564 92(91)	J m mol ⁻¹	7.6×10^{-9}
molar gas constant	R	8.314 472(15)	J mol ⁻¹ K ⁻¹	1.7×10^{-6}
Boltzmann constant R/N_A	k	$1.380\,6503(24)\times 10^{-23}$	J K ⁻¹	1.7×10^{-6}
in eV K ⁻¹		$8.617\,342(15)\times 10^{-5}$	eV K ⁻¹	1.7×10^{-6}
	k/b	$2.083\,6644(36)\times 10^{10}$	Hz K ⁻¹	1.7×10^{-6}
	k/bc	69.503 56(12)	m ⁻¹ K ⁻¹	1.7×10^{-6}
molar volume of ideal gas RT/p $T=273.15\text{ K}, p=101.325\text{ kPa}$	V_m	$22.413\,996(39)\times 10^{-3}$	m ³ mol ⁻¹	1.7×10^{-6}
Loschmidt constant N_A/V_m $T=273.15\text{ K}, p=100\text{ kPa}$	n_0	$2.686\,7775(47)\times 10^{25}$	m ⁻³	1.7×10^{-6}
	V_m	$22.710\,981(40)\times 10^{-3}$	m ³ mol ⁻¹	1.7×10^{-6}
Sackur–Tetrode constant (absolute entropy constant) ^h $\frac{5}{2} + \ln[(2\pi m_u k T_1/h^2)^{3/2} k T_1/p_0]$ $T_1=1\text{ K}, p_0=100\text{ kPa}$	S_0/R	-1.151 7048(44)		3.8×10^{-6}
$T_1=1\text{ K}, p_0=101.325\text{ kPa}$		-1.164 8678(44)		3.7×10^{-6}
Stefan–Boltzmann constant $(\pi^2/60)k^4/\hbar^3 c^2$	σ	$5.670\,400(40)\times 10^{-8}$	W m ⁻² K ⁻⁴	7.0×10^{-6}
first radiation constant $2\pi\hbar c^2$	c_1	$3.741\,771\,07(29)\times 10^{-16}$	W m ²	7.8×10^{-8}
first radiation constant for spectral radiance $2\hbar c^2$	c_{1L}	$1.191\,042\,722(93)\times 10^{-16}$	W m ² sr ⁻¹	7.8×10^{-8}
second radiation constant $\hbar c/k$	c_2	$1.438\,7752(25)\times 10^{-2}$	m K	1.7×10^{-6}
Wien displacement law constant $b=\lambda_{\text{max}} T=c_2/4.965\,114\,231\ldots$	b	$2.897\,7686(51)\times 10^{-3}$	m K	1.7×10^{-6}

^aSee the “Internationally Adopted Values” table for the conventional value for realizing representations of the volt using the Josephson effect.

^bSee the “Internationally Adopted Values” table for the conventional value for realizing representations of the ohm using the quantum Hall effect.

^cValue recommended by the Particle Data Group [C. Caso *et al.*, Eur. Phys. J. C 3, 1 (1998)].

^dBased on the ratio of the masses of the W and Z bosons m_W/m_Z recommended by the Particle Data Group [C. Caso *et al.*, Eur. Phys. J. C 3, 1 (1998)]. The value for $\sin^2\theta_W$ they recommend, which is based on a particular variant of the modified minimal subtraction ($\overline{\text{MS}}$) scheme, is $\sin^2\theta_W(M_Z)=0.231\,24(24)$.

^eThe helion, symbol h, is the nucleus of the ³He atom.

^fThis 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 [C. Caso *et al.*, Eur. Phys. J. C 3, 1 (1998)], but with a standard uncertainty of 0.29 MeV rather than the quoted uncertainty of -0.26 MeV, +0.29 MeV.

^gThe numerical value of F to be used in coulometric chemical measurements is $96\,485.3432(76)$ [7.9×10^{-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 conventional values of the Josephson and von Klitzing constants K_{J-90} and R_{K-90} given in the “Internationally Adopted Values” table.

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

Internationally Adopted Values of Various Quantities

Quantity	Symbol	Value	Unit	Relative standard uncertainty u_r
molar mass of ^{12}C	$M(^{12}\text{C})$	12×10^{-3}	kg mol^{-1}	(exact)
molar mass constant ^a $M(^{12}\text{C})/12$	M_{u}	1×10^{-3}	kg mol^{-1}	(exact)
conventional value of Josephson constant ^b	$K_{\text{J-90}}$	483 597.9	GHz V^{-1}	(exact)
conventional value of von Klitzing constant ^c	$R_{\text{K-90}}$	25 812.807	Ω	(exact)
standard atmosphere		101 325	Pa	(exact)
standard acceleration of gravity	g_{n}	9.806 65	m s^{-2}	(exact)

^aThe relative atomic mass $A_r(\text{X})$ of particle X with mass $m(\text{X})$ is defined by $A_r(\text{X}) = m(\text{X})/m_{\text{u}}$, where $m_{\text{u}} = m(^{12}\text{C})/12 = M_{\text{u}}/N_{\text{A}} = 1 \text{ u}$ is the atomic mass constant, N_{A} is the Avogadro constant, and u is the (unified) atomic mass unit. Thus the mass of particle X is $m(\text{X}) = A_r(\text{X}) \text{ u}$ and the molar mass of X is $M(\text{X}) = A_r(\text{X})M_{\text{u}}$.

^bThis is the value adopted internationally for realizing representations of the volt using the Josephson effect.

^cThis is the value adopted internationally for realizing representations of the ohm using the quantum Hall effect.

CODATA Recommended Values of Energy Equivalents – 1998

Relevant unit				
	J	kg	m^{-1}	Hz
1 J	(1 J) = 1 J	(1 J)/ c^2 = 1.112 650 056 $\times 10^{-17}$ kg	(1 J)/ hc = 5.034 117 62(39) $\times 10^{24}$ m^{-1}	(1 J)/ h = 1.509 190 50(12) $\times 10^{33}$ Hz
1 kg	(1 kg) c^2 = 8.987 551 787 $\times 10^{16}$ J	(1 kg) = 1 kg	(1 kg) c/h = 4.524 439 29(35) $\times 10^{41}$ m^{-1}	(1 kg) c^2/h = 1.356 392 77(11) $\times 10^{50}$ Hz
1 m^{-1}	(1 m^{-1}) hc = 1.986 445 44(16) $\times 10^{-25}$ J	(1 m^{-1}) h/c = 2.210 218 63(17) $\times 10^{-42}$ kg	(1 m^{-1}) = 1 m^{-1}	(1 m^{-1}) c = 299 792 458 Hz
1 Hz	(1 Hz) h = 6.626 068 76(52) $\times 10^{-34}$ J	(1 Hz) h/c^2 = 7.372 495 78(58) $\times 10^{-51}$ kg	(1 Hz)/ c = 3.335 640 952 $\times 10^{-9}$ m^{-1}	(1 Hz) = 1 Hz
1 K	(1 K) k = 1.380 6503(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) = 1.602 176 462(63) $\times 10^{-19}$ J	(1 eV)/ c^2 = 1.782 661 731(70) $\times 10^{-36}$ kg	(1 eV)/ hc = 8.065 544 77(32) $\times 10^5$ m^{-1}	(1 eV)/ h = 2.417 989 491(95) $\times 10^{14}$ Hz
1 u	(1 u) c^2 = 1.492 417 78(12) $\times 10^{-10}$ J	(1 u) = 1.660 538 73(13) $\times 10^{-27}$ kg	(1 u) c/h = 7.513 006 658(57) $\times 10^{14}$ m^{-1}	(1 u) c^2/h = 2.252 342 733(17) $\times 10^{23}$ Hz
1 E_{h}	(1 E_{h}) = 4.359 743 81(34) $\times 10^{-18}$ J	(1 E_{h})/ c^2 = 4.850 869 19(38) $\times 10^{-35}$ kg	(1 E_{h})/ hc = 2.194 746 313 710(17) $\times 10^7$ m^{-1}	(1 E_{h})/ h = 6.579 683 920 735(50) $\times 10^{15}$ Hz

CODATA Recommended Values of Energy Equivalents – 1998

Relevant unit				
	K	eV	u	E_{h}
1 J	(1 J)/ k = 7.242 964(13) $\times 10^{22}$ K	(1 J) = 6.241 509 74(24) $\times 10^{18}$ eV	(1 J)/ c^2 = 6.700 536 62(53) $\times 10^9$ u	(1 J) = 2.293 712 76(18) $\times 10^{17}$ E_{h}
1 kg	(1 kg) c^2/k = 6.509 651(11) $\times 10^{39}$ K	(1 kg) c^2 = 5.609 589 21(22) $\times 10^{35}$ eV	(1 kg) = 6.022 141 99(47) $\times 10^{26}$ u	(1 kg) c^2 = 2.061 486 22(16) $\times 10^{34}$ E_{h}
1 m^{-1}	(1 m^{-1}) hc/k = 1.438 7752(25) $\times 10^{-2}$ K	(1 m^{-1}) hc = 1.239 841 857(49) $\times 10^{-6}$ eV	(1 m^{-1}) h/c = 1.331 025 042(10) $\times 10^{-15}$ u	(1 m^{-1}) hc = 4.556 335 252 750(35) $\times 10^{-8}$ E_{h}
1 Hz	(1 Hz) h/k = 4.799 2374(84) $\times 10^{-11}$ K	(1 Hz) h = 4.135 667 27(16) $\times 10^{-15}$ eV	(1 Hz) h/c^2 = 4.439 821 637(34) $\times 10^{-24}$ u	(1 Hz) h = 1.519 829 846 003(12) $\times 10^{-16}$ E_{h}
1 K	(1 K) = 1 K	(1 K) k = 8.617 342(15) $\times 10^{-5}$ eV	(1 K) k/c^2 = 9.251 098(16) $\times 10^{-14}$ u	(1 K) k = 3.166 8153(55) $\times 10^{-6}$ E_{h}
1 eV	(1 eV)/ k = 1.160 4506(20) $\times 10^4$ K	(1 eV) = 1 eV	(1 eV)/ c^2 = 1.073 544 206(43) $\times 10^{-9}$ u	(1 eV) = 3.674 932 60(14) $\times 10^{-2}$ E_{h}
1 u	(1 u) c^2/k = 1.080 9528(19) $\times 10^{13}$ K	(1 u) c^2 = 931.494 013(37) $\times 10^6$ eV	(1 u) = 1 u	(1 u) c^2 = 3.423 177 709(26) $\times 10^7$ E_{h}
1 E_{h}	(1 E_{h})/ k = 3.157 7465(55) $\times 10^5$ K	(1 E_{h}) = 27.211 3834(11) eV	(1 E_{h})/ c^2 = 2.921 262 304(22) $\times 10^{-8}$ u	(1 E_{h}) = 1 E_{h}

(continued from page 7)

follows from the expression $e = (2\alpha h/\mu_0 c)^{1/2}$, the mass of the electron from $m_e = 2R_\infty h/c\alpha^2$, and the Avogadro constant from $N_A = c\alpha^2 A_1(e)M_u/2R_\infty h$, where $\mu_0 = 4\pi \times 10^{-7} \text{ N A}^{-2}$, $c = 299\,792\,458 \text{ m s}^{-1}$, and $M_u = 10^{-3} \text{ kg/mol}$, are the exactly known magnetic constant, speed of light in vacuum, and molar mass constant, respectively. The uncertainties of such derived values are obtained from the uncertainties and covariances of the adjusted constants.

The improvement in our knowledge of the values of the constants represented by the 1998 CODATA set of recommended values is truly impressive. Still, it is not as well founded as one might like. Specifically, there is little redundancy among some of the key input data of the 1998 adjustment. As indicated above, α , h , and R play an especially critical role in the determination of many constants, yet the recommended value of each is to a large extent determined by a single input datum or, at best, two input data with rather different standard uncertainties u and hence rather different weights $1/u^2$. In the case of α , the input data are merely the single experimental value of α_e and the single calculated value of the mass-independent eighth-order coefficient $A_1^{(8)}$ in the QED-based theoretical expression for α_e . In the case of h , the input data are the two watt-balance values of $K_J^2 R_K$, with uncertainties that differ by a factor of about 2.3. And in the case of the molar gas constant, the input data are the two values of R based on speed-of-sound measurements in argon using a resonator and an interferometer with uncertainties that differ by about a factor of 4.7. The experimental and theoretical work required to solidify and continue the progress of the last 13 years is thus clear: We must obtain new input data related to α , h , and R with uncertainties no larger than their current uncertainties, and eventually with significantly smaller uncertainties.

The existence of the Web has dramatically changed the availability of information—we can expect to have the latest data available electronically only a mouse-click away. In fact, the new 1998 CODATA set of recommended values was available at the NIST Web site mentioned above seven months before the appearance of the first printed version. Because of the Web and the new modes of work and thought it has engendered, and because experimental and theoretical data that influence our knowledge of the values of the constants appear nearly continuously, the CODATA task group has concluded that 13 years between adjustments is no longer acceptable. (The first set of CODATA recommended values of the constants was issued in 1973,³ 13 years before the second set in 1986 and 26 years before the 1998 set.) Thus, in the future, by taking advantage of the high degree of automation we have incorporated in the 1998 adjustment, CODATA plans to issue a new set of recommended values every four years, or more frequently if new data become available that have a significant impact on the values of the constants. You can thus expect a much shorter wait to see the next revision of this article in the *PHYSICS TODAY Buyers' Guide*.

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References

1. P. J. Mohr and B. N. Taylor, *J. Phys. Chem. Ref. Data* **28**, 1713 (1999); *Rev. Mod. Phys.* **72**, 351 (2000).
2. E. R. Cohen and B. N. Taylor, *Rev. Mod. Phys.* **59**, 1121 (1987).
3. E. R. Cohen and B. N. Taylor, *J. Phys. Chem. Ref. Data* **2**, 663 (1973). ■

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