ing a vicious cycle in which developing countries that lag in S&T capacity fall further behind, as industrialized nations with financial resources and a trained scientific work force exploit new knowledge and technologies more quickly and intensively.

These deficits can leave entire developing economies behind. And when nations need to respond to diseases such as HIV or SARS, or make decisions about issues such as stem-cell research or genetically modified foods, this lack of S&T infrastructure can breed unfounded fear and social discord.

The report asserts that there is no reason why, in an era in which air travel and the Internet already tightly interconnect national economies, S&T capacity building should not be a worldwide priority. Developing countries must begin strengthening their national capacities. "Given the current rate of change in science and technology, there is no time to waste if the majority of humanity is not to suffer further marginalization," the report concludes.

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New Best Estimates of the Values of the Fundamental Constants

by Ian Mills

The so-called fundamental constants of nature have an increasing importance in science today. Fundamental constants refer to the Planck constant *h*, the Boltzmann constant k_B, the elementary charge *e*, and a number of others listed on the next page. These quantities play a key role in most of the basic relations involved in modern physics and chemistry, and they provide the ultimate standard of reference for all quantitative measurements. For these reasons, the scientists strive to determine the values of these constants with ever greater accuracy in terms of the base units of our system of measurement, such as the kilogram, metre, second, ampere, and kelvin—the base units of the SI, the International System of units. The Consultative Committee for Units (of the International Committee on Weights and Measures, BIPM/CCU) advises the Comité International des Poids et Mesures on defining (or redefining) each of the base units of the SI in terms of the fundamental constants rather than in terms of material artefacts or time intervals related to the rotation of the earth. Today, some, but not all, of the base units of the SI are defined in this way, and we are working on the remainder.

In December 2003, new best estimates of the fundamental constants were released. These are compiled and published with the authority of a CODATA committee that exists for this purpose, but in practice they are produced (on this occasion) by Barry Taylor and Peter Mohr at the U.S. National Institute for Standards and Technology (NIST), in Gaithersburg, MD. These new values displace the 1998 values (also produced by Mohr and Taylor), which have been in use for the last four years. The 1998 values in their turn displaced the 1986 best estimates (which were produced by Cohen and Taylor), which were in use for the 12 years from 1986 to 1998.

As the years go by, scientists determine these constants with ever-greater accuracy. The uncertainties associated with the best estimates of the fundamental constants have mostly been falling by roughly an order of magnitude each 10 years, as new and improved experimental measurements make it possible to determine the constants with ever greater precision. The table on page 18 contains the most interesting constants for chemistry from the new 2002 best estimates, comparing the 1986, 1998, and 2002 values. The complete list is available from the NIST Web site, <http://physics.nist.gov/constants>, and will be published in an archive journal early in 2004.

Determining a set of best estimates of this kind is not simple, because there are numerous theoretical equations relating the constants and there are many different experiments that provide information on one or another of the constants. Thus, they all have to be determined from a single giant least-squares calculation, using all the available data with their uncertainties and all the known theoretical relations. This is why they are only revised at wide intervals. However, Barry Taylor says that they hope to revise them at more frequent intervals from now on, perhaps every three or four years. There is also a table of correlation coefficients among the various values on the NIST Web site.

Note that a few of these constants are exact (have zero uncertainty), because of the way that the units are defined. Thus, the metre is now defined in such a way as to make the speed of light c_0 exact, and the ampere is defined in such a way as to make the magnetic constant μ_0 (the permeability of free space) exact. The relation $\varepsilon_0\mu_0 = 1/c_0^2$ then implies that the electric constant ε_0 (the permittivity of free space) is also exact.

As an example of the relations that we believe to hold between the constants, the Boltzmann constant, k, the gas constant, R, and the Avogadro constant, N_A, are related by the equation: $R = N_A\ k$. Although these three constants might be independently determined by different methods, there would be no sense in adopting values that did not fit this relation.

A more complicated relation is that between the Planck constant, h, and the Avogadro constant, N_A:

$$h = \frac{c_0\, A_r(e)\, M_u\, \alpha^2}{2\, R_\infty\, N_A}$$

where c_0 is the speed of light in vacuum, $A_r(e)$ is the relative electron mass (on the atomic mass scale, referred to m(12C)/12), M_u is equal to 1 g/mol (the standard molar mass), α is the fine structure constant, and R_∞ is the Rydberg constant. Because the best measurements of the Avogadro constant and the Planck have a relative standard uncertainty of about 10^{-7}, whereas all the other constants in this relation are either exact or are known to about 10^{-9}, we require the best estimates of h and N_A to satisfy this relation within their mutual uncertainties. Unfortunately recent measurements of the value of h (from Watt balance experiments) and N_A (from the X-ray crystal density experiment) are not quite consistent within the uncertainty budget estimated for each value, and this has led to an *increase* in the uncertainty of these two constants since the 1998 appraisal (which is exceptional!). There is then a

Fundamental Constants 2002

Quantity	***Symbol***	***2002 Value (standard uncertainty)****	***Unit***	***Relative standard uncertainty u_r***
speed of light in vacuum	c_0	299 792 458	$\mathrm{m\ s^{-1}}$	(exact)
magnetic constant	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\ m^{-1}}$	(exact)
electric constant	$\varepsilon_0 = 1/\mu_0 c_0^2$	8.854 187 817 …	$\times 10^{-12}\ \mathrm{F\ m^{-1}}$	(exact)
Planck constant	h	6.626 069 3 (11)	$\times 10^{-34}\ \mathrm{J\ s}$	1.7×10^{-7}
elementary charge (charge on a proton)	e	1.602 176 53 (14)	$\times 10^{-19}\ \mathrm{C}$	8.5×10^{-8}
electron rest mass	m_e	9.109 382 6 (16)	$\times 10^{-31}\ \mathrm{kg}$	1.7×10^{-7}
proton rest mass	m_p	1.672 621 71 (29)	$\times 10^{-27}\ \mathrm{kg}$	1.7×10^{-7}
atomic mass constant (dalton, or unified atomic mass unit, $m(^{12}C)/12$)	m_u = Da = u	1.660 538 86 (28)	$\times 10^{-27}\ \mathrm{kg}$	1.7×10^{-7}
Avogadro constant	$L,\ N_A$	6.022 141 5 (10)	$\times 10^{23}\ \mathrm{mol^{-1}}$	1.7×10^{-7}
Boltzmann constant	$k,\ (k_B)$	1.380 650 5 (24)	$\times 10^{-23}\ \mathrm{J\ K^{-1}}$	1.8×10^{-6}
Faraday constant	F	96 485.33 83 (83)	$\mathrm{C\ mol^{-1}}$	8.6×10^{-8}
gas constant	R	8.314 472 (15)	$\mathrm{J\ mol^{-1}\ K^{-1}}$	1.7×10^{-6}
fine structure constant	α	7.297 352 568 (24)	$\times 10^{-3}$	3.3×10^{-9}
Bohr radius	a_0	0.529 177 210 8 (18)	$\times 10^{-10}\ \mathrm{m}$	3.3×10^{-9}
Hartree energy	E_h	4.359 744 17 (75)	$\times 10^{-18}\ \mathrm{J}$	1.7×10^{-7}
Rydberg constant	R_∞	10 973 731.568 525 (73)	$\mathrm{m^{-1}}$	6.6×10^{-12}
Bohr magneton	μ_B	9.274 009 49 (80)	$\times 10^{-24}\ \mathrm{J\ T^{-1}}$	8.6×10^{-8}
Landé g factor for free electron	g	2.002 319 304 371 8 (75)		3.8×10^{-12}
nuclear magneton	μ_N	5.050 783 43 (43)	$\times 10^{-27}\ \mathrm{J\ T^{-1}}$	8.6×10^{-8}
Relative atomic mass of the electron	$A_r(e)$	5.485 799 094 5 (24)	$\times 10^{-4}$	4.4×10^{-10}
Newtonian constant of gravitation	G	6.674 2 (10)	$\times 10^{-11}\ \mathrm{m^3\ kg^{-1}\ s^{-2}}$	1.5×10^{-4}

*The standard uncertainty given in parenthesis (i.e. the estimated standard deviation of the value quoted), applies to the least significant digits of each constant.

Source: The National Institute of Standards and Technology (NIST) Reference on Constants, Units, and Uncertainties Web page <http://physics.nist.gov/ccu/constants>.

consequent increase in the estimated uncertainties of several other constants.

These constants are described as the 2002 best estimates, although the values have only just been released in December 2003, because the cut-off date for data included in the analysis was 31 December 2002.

References

The NIST Web site: http://physics.nist.gov/constants

Mohr and Taylor, *J. Phys. Chem. Ref. Data* **28**, pp 1715–1852 (1999); also in *Rev. Mod. Phys.* **72**, pp 351–495, No 2, April 2000 (which is essentially the same paper) ; these two papers describe the 1998 best estimates, but they contain a lot of useful information.

See also the *SI Brochure* 7th edition 1998, ed. Mills and Quinn, available from the BIPM Web site <www.bipm.org/en/publications/brochure>, for information on the definition of the SI base units. The brochure is also available as a printed book (ISBN 92-822-2154-7), which can be ordered from the BIPM Web site.

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Comparison of 1986, 1998, and 2002 values

Quantity	***Symbol***	***1986 Value***	***1998 Value***	***2002 Value***	***Unit***
Planck constant	h	6.626 075 5 (40)	6.626 068 76 (52)	6.626 069 3 (11)	$\times10^{-34}$ J s
elementary charge (charge on a proton)	e	1.602 177 33 (49)	1.602 176 462 (63)	1.602 176 53 (14)	$\times10^{-19}$ C
electron rest mass	m_e	9.109 389 7 (54)	9.109 381 88 (72)	9.109 382 6 (16)	$\times10^{-31}$ kg
proton rest mass	m_p	1.672 623 1 (10)	1.672 621 58 (13)	1.672 621 71 (29)	$\times10^{-27}$ kg
atomic mass constant (dalton, or unified atomic mass unit, $m(^{12}C)/12$)	m_u = Da = u	1.660 540 2 (10)	1.660 538 73 (13)	1.660 538 86 (28)	$\times10^{-27}$ kg
Avogadro constant	L, N_A	6.022 136 7 (36)	6.022 141 99 (47)	6.022 141 5 (10)	$\times10^{23}$ mol^{-1}
Boltzmann constant	k, (k_B)	1.380 658 (12)	1.380 650 3 (24)	1.380 650 5 (24)	$\times10^{-23}$ J K^{-1}
Faraday constant	F	9.648 530 9 (29)	9.648 534 15 (39)	9.648 533 83 (83)	$\times10^{4}$ C mol^{-1}
gas constant	R	8.314 510 (70)	8.314 472 (15)	8.314 472 (15)	J mol^{-1} K^{-1}
fine structure constant	α	7.297 353 08 (33)	7.297 352 533 (27)	7.297 352 568 (24)	$\times10^{-3}$
Bohr radius	a_0	0.529 177 249 (24)	0.529 177 208 3 (19)	0.529 177 210 8 (18)	$\times10^{-10}$ m
Hartree energy	E_h	4.359 748 2 (26)	4.359 743 81 (34)	4.359 744 17 (75)	$\times10^{-18}$ J
Rydberg constant	R_∞	10 973 731.534 (13)	10 973 731.568 548 (83)	10 973 731.568 525 (73)	m^{-1}
Bohr magneton	μ_B	9.274 015 4 (13)	9.274 008 99 (37)	9.274 009 49 (80)	$\times10^{-24}$ J T^{-1}
Landé g factor for free electron	g	2.002 319 304 386 (20)	2.002 319 304 373 7 (82)	2.002 319 304 371 8 (75)	
nuclear magneton	μ_N	5.050 786 6 (17)	5.050 783 17 (20)	5.050 783 43 (43)	$\times10^{-27}$ J T^{-1}
Newtonian constant of gravitation	G		6.673 (10)	6.674 2 (10)	$\times10^{-11}$ m^3 kg^{-1} s^{-2}

The values are presented in a concise notation whereby the standard uncertainty is given in parenthesis next to the least significant digits to which it applies; for example, $h = 6.626\,069\,3\ (11)$ is the concise form of the expression $h = 6.626\,069\,3 \pm 0.000\,001\,1$

Up for Discussion

A forum for members and member organizations to share ideas and concerns.
Send your comments by e-mail to <edit.ci@iupac.org>.

This section of CI *provides a way for members and member organizations to share ideas and concerns. For this issue, the Japanese National Adhering Organization sent us, without prompting, the following report of activities of its National Committee for Chemistry. In publishing here a version of this report, we hope to echo the concerns of other organizations and facilitate consultation and dialogue, and the sharing of best practices.*

Chemistry in Japan—A Report from the National Committee for Chemistry

by Akio Yamamoto

The National Committee for Chemistry in Japan—a committee that belongs to the Science Council of Japan (SCJ), the NAO for IUPAC—comprises 61 members. The committee is charged with deliberating on "important matters related to chemistry and coordination of the research programs in and outside of Japan," and is therefore the link with IUPAC.

The committee members are selected based on recommendations from other chemistry-related societies. The committee, which has one of the largest memberships among other national committees of the Science Council of Japan, represents a broad cross section of the chemical community in Japan.

During the past several years, the committee has been involved in domestic and international efforts to promote chemistry. Between 2000 and 2003 the committee undertook a project to address problems facing the chemical community. After extensive discussions, the committee finalized the report and released it last year. Following is a summary of the report's recommendations.

Summary of the Report of the National Committee for Chemistry, The Science Council of Japan

The report's recommendations are divided into three parts directed to the government, the public, and fellow chemists.

Message to the Government

Among the issues the committee discussed, the following problems emerged as the most important.

- **Improvement of University Facilities is Urgently Needed—**Although we acknowledge the recent increase in research grants given to universities and other research institutions, we have to point out the unsatisfactory conditions of university buildings, particularly in chemistry-related departments. Space is often very limited, making laboratories dangerously congested. In order to meet international safety standards, it is urgent that these facilities be improved.
- **Support for Graduate Students Should be Improved—**A lack of support for Ph.D. students discourages many talented students from pursuing Ph.D. program. More scholarships, research assistantships, and teaching assistantships should be provided for these students.
- **Information Databases Should be Upgraded—**The present compilation of scientific and engineering data is unsatisfactory to allow the nation to make reasonable judgments regarding science policy. Information databases in universities should be improved to track the progress of science and engineering.

Message to the Public

- **The committee disagrees with current usage of the term "chemical substances" in the mass media.** The mass media often use the term "chemical substances" to refer to synthetic compounds, especially those that are poisonous or harmful. However, the term "chemical substances," when properly used, applies to any substance on earth; water, table salt, sugar, and air are all chemical substances. There are many natural substances that are quite poisonous and any seemingly safe substance can be harmful to the human body when taken in excess. Certainly there have been incidents in which chemicals were carelessly or inadvertently released to the environment and caused great harm. It is quite clear that chemists should make every endeavor to keep the environment unspoiled. However, we discourage incorrect usage of the term "chemical substances" because it creates an incorrect image of chemistry.
- **When discussing the risks involved with chemicals, the mass media should take into account the ratios of risk to benefit and of cost to benefit.** Nothing can be absolutely safe. Therefore, the committee requests that the mass media present a