THE 2006 ADJUSTMENT OF THE FUNDAMENTAL CONSTANTS: LOOKING TOWARDS 2010

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Abstract

A new set of values of the basic fundamental constants has been recommended by the Committee on Data for Science and Technology (CODATA) (http://physics.nist.gov/cuu/Constants/). It is based on a least-squares adjustment that incorporates new data that became available before the closing date of 31 December 2006 (known as the 2006 LSA). A number of key advances in experiment and theory have led to significant improvements in our knowledge of the values of the constants. The consequences of the new results and how the values were determined will be discussed.

Introduction

CODATA was established in 1966 as an interdisciplinary committee of the International Council of Scientific Unions (now the International Council for Science). Three years later the Task Group on Fundamental Constants was created within CODATA to periodically provide a self-consistent set of internationally recommended values for the basic constants and conversion factors of physics and chemistry. The complete 2006 CODATA set of more than 300 recommended values together with a detailed description of the data and their analysis has been accepted for publication and posted on the web [1]. The new set of recommended values replaces its immediate predecessor that resulted from the 2002 adjustment [2].

New data and consequences

New information available before the cut off date of Dec. 31, 2006, includes the following:

a significantly improved experimental value of the electron magnetic moment a_e with a relative standard uncertainty $u_r = 6.5 \times 10^{-10}$ [3];

an improved theoretical expression based on quantum electrodynamics (QED) for a_e [4] that, together with the new experimental value of a_e, leads to a new recommended value of the fine-structure constant α with $u_r = 6.8 \times 10^{-10}$;

an accurate value of the quotient $h/m(^{87}\text{Rb})$ where h is the Planck constant and $m(^{87}\text{Rb})$ is the mass of the rubidium-87 atom $u_r = 1.3 \times 10^{-8}$ [5], that provides a value of α with $u_r = 6.6 \times 10^{-9}$ independent of QED theory;

a new accurate and consistent value of the product $K_J^2 R_K = 4/h$ [6] - where K_J is the Josephson constant and R_K is the von Klitzing constant - from a moving coil watt balance that leads to a new recommended value of h with $u_r = 5.0 \times 10^{-8}$;

combined x-ray optical interferometer (XROI) results for the lattice spacing parameter, d_{220}, for nearly perfect single crystals of silicon that include four absolute determinations [7];

results on masses of nuclei from the 2003 Atomic Mass Evaluation of the Atomic Mass Data Center [8];

measurements of transition frequencies in antiprotonic helium [9] that together with theoretical expressions for the frequencies [10] provide a value of the relative atomic mass of the electron, $A_r(e)$;

improved measurements of the relative atomic masses of ^{2}H [11], ^{3}H [12], and ^{4}He [13];

improved measurements of the nuclear magnetic resonance (NMR) frequencies of the deuteron (d) and proton (p) in the hydrogen-deuterium (HD) molecule and of the triton (t) and p in the hydrogen-tritium molecule (HT) [14,15] that i) lead to a reduction in the uncertainty of the recommended values of the deuteron-electron and deuteron-proton magnetic moment ratios μ_d/μ_e and μ_d/μ_p, and that ii) combined with the relative atomic mass of ^{3}H, lead to the new inclusion of recommended values for quantities associated with the triton;

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improved theoretical expressions for H and D energy levels.

Data analysis

The CODATA Task Group on Fundamental Constants oversees the data selection and methodology of the adjustment of the recommended values of the constants. In general, the adjustment is based on a multivariable least squares analysis [16] that incorporates the variances and covariances of the relevant input data. Data that contribute less than 1 % are not included in the final adjustment. The case of discrepant data, however, requires further oversight of the Task Group. There were two major inconsistencies in the input data for the 2006 LSA.

Three of the absolute d_{220} values agree among themselves, however a fourth value disagrees, although it is in reasonable agreement with the d_{220} value implied by an accurate x-ray measurement of $h/(m_n d_{220})$, where m_n is the mass of the neutron. After due consideration, the CODATA task group decided that all five of these input data should be considered for retention, but that each of their *a prori* assigned uncertainties should be multiplied by a factor such that each of their residuals from the adjustment is at or below 2. This resulting multiplicative factor is 1.5.

The five implied experimental values of h from three moving coil watt balances, a mercury-electrometer, and a capacitor volt-balance are all in excellent agreement, but disagree with the implied value of h from the experimental value of the molar volume of silicon, V_m(Si). As was done with d_{220}, the six data were weighted by a multiplicative factor to reduce the residuals to 2 or below. By coincidence, this factor is also 1.5.

Results and Conclusions

There is limited redundancy among some key input data for the 2006 LSA. The low uncertainty of the new implied value of α from the measurement of a_e and improved QED theory eliminates all but two input data associated with α, yet relies on a single value of the eighth-order QED coefficient $A_1^{(8)}$, as does the next most accurate implied value of α. The determination of h is dominated by moving coil watt balances and in particular the new result listed above. Finally there are two key input data for the molar gas constant, R, both from speed of sound measurements in argon, however one has an uncertainty that is smaller than the other by a factor of 4.7.

The CODATA Task Group will provide a new set of recommended values every four years. New experimental and theoretical data have already become available since the cut-off date of December 31, 2006. In particular a correction to $A_1^{(8)}$ has been discovered [17] and there is a new moving coil watt balance result [18]. These and other new data available before December 31, 2010, will have an important impact on the 2010 adjusted values of the fundamental constants that are being considered to be defined as exact for a redefinition of the International System of Units in 2011 [19].

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