Report on the Meeting of the CODATA Task Group on Fundamental Constants
Document TGFC-19-03

9:30 a.m. – 15:00 p.m. Monday, 7 October 2019

Bureau International des Poids et Mesures
Pavillon de Breteuil, F-92312 Sèvres, France

Prepared by

Barry Wood, National Research Council (Canada),
David Newell, National Institute of Standards and Technology (USA) and
Krzysztof Pachucki, University of Warsaw (Poland)

1. Opening of the meeting and introductions

The meeting opened at 9:30 AM Monday morning and introductions were made. Members of the Task Group on Fundamental Constants in attendance were: David Newell (chair), Krzysztof Pachucki (co-chair), François Nez, Barry Wood, Savely Karshenboim, Andrey Surzhykov, Eite Tiesinga, Kenichi Fujii, Helen Margolis and Randolf Pohl.

The following members sent their regrets: Peter Mohr, Estefania de Mirandés, and Franco Cabiati, Jifeng Qu and Meng Wang.

Present as observers were: Richard Davis and Michael Stock (BIPM), Enrico Massa (INrim), Alan Steele and Matthew Brown (NRC), David Flater (NIST), Nadine de Courtenay and Fabien Gregis (U of Paris).

2. Review of the agenda

The agenda, TGFC/19-01, was reviewed. It was noted that items 4c and 4h are overlapping or at least very interconnected. This was agreed and will be reflected in the meeting minutes and the unchanged agenda was accepted.

3. Review of the report of the Task Group meeting held on Saturday, 7 July 2018, LNE, France

The minutes of the last meeting, (TGFC/18-02 and TGFC/19-02), were approved without change and will be posted on the unrestricted website.

4. The 2018 CODATA adjustment of the fundamental constants

The CODATA 2018 Adjustment was posted online on May 20, 2019 in coordination with the 2019 revisions to the International System of Units. The CODATA 2018 Adjustment is the first adjustment since fixing the values of the Planck, Avogadro and Boltzmann constants and the value of the elementary charge, all without uncertainties.

Newell presented TGFC/19-04 which starts off by summarizing the differences concerning the 2018 Least Squares Adjustment with respect to the changes in the SI implemented on May 20, 2019. This basically means that h, e, k, and N_A are now exact and μ_0 and ε_0 are no longer exact. As well, the molar mass of a particle is now expressed by

$$N_A A_r(p)\frac{1}{A}$$

The 2018 adjustment is the first in which the Planck constant and molar gas constant are no longer adjusted variables and this directly impacts many of the fundamental constants of earlier adjustments.

Tiesinga and Newell reviewed the general concepts of the least squares adjustment and described the manner in which uncertainties of theoretical models are introduced.

R. Pohl commented on the fact the value of the magnetic constant, μ_0, has changed between the 2017 Special Adjustment and the 2018 Adjustment. It was explained that this occurred because the value of the fine structure constant had changed slightly between these two adjustments.

Wood congratulated the Task Group on achieving this timely release despite the tight constraints.

a. **Gravitational constant *G***

Newell gave a presentation (TFGC/19-4) which summarises all of the new data for the 2018 Adjustment and in particular outlined the status of gravitational measurements, slide 6. There are two new torsion pendulum measurements from Huazhong University of Science and Technology, $HUST_A$-18 and $HUST_T$-18, using the time-of-swing method and the angular-acceleration-feedback method. The correlation between the two measurements is claimed to be 6.8%.

There is also a new value of the JILA experiment, JILA-18, which primarily revises an Abbe correction and makes a correction in the mass rotation calculation during the pendulum swing. This result has a slightly shifted value and an increase in uncertainty by a factor of 1.8.

Reanalysis of the entire ***G*** data set results in a new recommended value with a relative uncertainty of 2.2×10^{-5} using an expansion factor of 3.9.

Newell mentioned that the BIPM and JILA systems are now both at NIST and that first results may become available in a year.

S. Karshenboim commented that the task group may have to attract another big *G* expert to keep pace with the growing data set.

b. **Fine-structure constant α**

Tiesinga explained introduced the fine structure constants with slide 7. Karshenboim, Pachucki and Tiesinga spent a few minutes discussing the linkage of electron mass and Cs mass.

In summary there are no new measurements of the anomaly (g-2) of the free electron but there are some improvements in the theory. Slide 9 shows the contributing data, as well as the evolution of the fractional uncertainty over time.

In the revised SI the recent atomic recoil measurement of the cesium recoil performed at U. C. Berkeley (Parker *et al*, Science 360, 191 (2018) is now a measurement of the atomic mass of the Cs atom.

c. **Finite nuclear size in regular hydrogen spectroscopy**
There has been recent theory improvements summarized by Yerokhin, Pachucki, Patkos, Annalen der Physik **531**, 1800324 (2019).

d. **Relative atomic masses A_r(X)**
Newell outlined the situation about relative atomic and fundamental particle masses, slide 10, and their application of the 2018 adjustment. While there is not new data since the previous Task Group meeting, Newell felt that it was useful to review the status in light of the revised SI. Perhaps most importantly the expansion factor for $A_r(H)$ and $\omega_c(^{12}C^{6+})/\omega_c(p)$ were discussed. Karshenboim pointed out that determination of light atomic masses can be performed in coordination with AME. This will be further discussed during 2020 CODATA TGFC meeting.

e. **Magnetic moment ratios**
Newell outlined slide 11, the magnetic moment ratios as it applied to the 2018 Adjustment. Again there is no new data since the previous meeting but the analysis for the 2018 Adjustment is somewhat changed.

f. **Magnetic moment of the muon**
The magnetic moment of the muon was discussed, see slide 12. The theory and experiment results of the anomaly of the muon are inconsistent and it was decided at the last meeting that only the experimental value would be used in the 2018 Adjustment. However, if the theory result were included, an expansion factor of 1.65 would be needed. It was decided (votes 8 yes, 1 no) to include the muon magnetic moment anomaly in the CODATA adjustment.

g. **Bound-state g-factors for ground-state hydrogen-like C and Si**
Evaluation of the fine structure constant via recoil measurements requires knowledge of the specific mass ratios, which in turn are determined from the bound state g factor of the electron in hydrogenic C^{5+} and to a lesser degree Si^{13+}, see slide 11. This is most accurately done theoretically and recent improvements include Karshenboim and Ivanov, PRA 97, 022506 (2018).

h. **Rydberg constant R_∞ and the proton radius r_p**
The subjects of the Rydberg constant R_∞ and the proton radius r_p have recently received a lot of attention and review, see slides 14-18. Of note in 2019 there is the 2S-2P Lamb shift experiment Bezginov et al. Science 365, 1007 (2019) and the review of the theory Yerokhin, Pachucki, Patkos, Ann. Phys. 531, 1800324 (2019).

- **Muonic systems**
  Perhaps the most significant change of the 2018 Adjustment is the decision to include the experimental data for the Lamb shift of muonic hydrogen and deuterium, as well as the theoretical evaluation of these transitions, see slide 14.

- **Hydrogen and deuterium energy levels**
  Recent data is listed on slide 16 and the current data set is shown in slide 16.

- **e-p scattering**
  Recent work has been done on re-analysis of the existing e-p data set, see slide 17. From this work an inputs data point of the proton charge radius of r_p= 0.880(20) fm is estimated.

i. **final analysis**

Slide 18 summarizes the Task Group's present understanding of the proton radius puzzle along with its impact on the Rydberg constant. By considering the relative uncertainty correlations between the different data sets, particularly of muonic hydrogen and regular hydrogen spectroscopies, the discrepancy has been reduced over the past four years. With this analysis the Rydberg constant has a relative uncertainty of 1.9×10^{-12} and the proton charge radius 0.8414(19) fm.

Tiesinga outlined the manner in which uncertainties in theoretical models are included in the adjustment analysis and in the correlations between input data. While this is not a new process it has generated questions in the past and the authors felt that it should be clarified for the 2018 adjustment.

5. Publication of the CODATA 2018 Adjustment of the fundamental constants

While the online version of the CODATA 2018 Adjustment was posted on May 20, 2019, Newell noted that the manuscript was still in preparation and publication was expected sometime in the spring of 2020.

6. Other topics – CCU agenda items

CCU had previously asked the CODATA TGFC for an opinion on redefinition of the "unit" document TGFC/18-02. At the last meeting the TGFC voted for using the old definition from 8th edition of the Si Brochure.

While there was some limited discussion of the next three topics, see slides 24-29, the general feeling was that these matters were best left for the CCU meeting of the next day, especially since the Task group has not been formally asked for specific opinions.

a. Discussion on the definition of the term 'unit'

b. Discussion on angles and dimensionless quantities

c. Discussion on the SI in the digital world

d. Discussion on the possible extension of the available range of SI prefixes

7. Other Topics

There was discussion about including the lattice spacing of ideal, defect-free, impurity-free, natural abundance silicon somewhere in future adjustments, see slide 19. However, there was concern that neither the Task Group nor a general user would know the defects, impurities or isotope abundance of a typical sample

and thus quantifying the uncertainty would be problematic. A consensus was not reached at this meeting.

8. Task Group administration

a. Upcoming workshops to endorse

Karshenboim mentioned that the next PSAS conference is 2020 in Wuhan, China. The workshop has been endorsed by the TGFC.

b. Membership

It was announced at the start of the meeting that Randolf Pohl has been appointed as member of the Task Group. David Newell is stepping down as Task Group chairman and Eite Tiesinga and Krzysztof Pachucki will become CoChairs of the CODATA TGFC.

9. Date and location of the next Task Group meeting

There was some discussion about where the next meeting will be held since CPEM is no longer convenient for many members. Surzhykov stated that PTB would be available. Sometime after the meeting this was confirmed and the next meeting is now scheduled for Monday-Tuesday, October19-20, 2020 at PTB Braunschweig, Germany.

10. Adjournment

The meeting was adjourned at 13:30.