Report on the Meeting of the CODATA Task Group on Fundamental Constants

9:30 a.m. – 3:30 p.m. Monday, 4 September 2017
BIPM
Prepared by B. Wood, National Research Council and
Krzysztof Pachucki, University of Warsaw

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), Barry Wood (vice chair), Kenichi Fujii, Peter Mohr, François Nez, Barry Taylor, Estefania de Mirandés, Joachim Fischer, Franco Cabiati, Savely Karshenboim, Krzysztof Pachucki, Terry Quinn, Helen Margolis

The following members sent their regrets: Zhang Zhonghua and Meng Wang.

Present as observers were: Joachmin Ullrich (CIPM, CCU and PTB), Martin Milton (Director of BIPM), Andrey Surzhykov and Horst Bettin (PTB), Carl Williams , Eite Tiesinga and Stephan Schlamminger (NIST), Enrico Massa (INRIM), Georges Audi and Wenjia Huang (CSNSM), Michael Stock, Richard Davis and Hao Fang, (BIPM), Jintao Zhang, Zhengkun Li and Jifeng Qu (NIM), Alan Steele (NRC).

2 Review of the agenda

The agenda, TGFC/17-01, was reviewed and accepted.

3 Review of the report of the Task Group meeting held on Saturday, 16 July 2016, Ottawa, Canada

The minutes of the last meeting, (TGFC/16-05), were approved without change and will be posted on the unrestricted website.

4 The CODATA 2017 Special Adjustment of h, e, k, and N_A

The summary and full documents of the 2017 Special Adjustment are listed as documents TGFC/17-02 and TGFC/17-03.

a. Relevant input data accepted for publication by 1 July, 2017

- Planck constant h and Avogadro constant N_A

Wood gave a presentation, TGFC/17-05, on the status of the Kibble balance determinations of the Planck constant. While there are at least twelve Kibble balance projects in various stages of development only four have published results since last year and they were included in the considerations for the 2017 special adjustment.

The NIM joule balance project has published a result with a relative uncertainty of 0.24×10^{-6}. However, this uncertainty was larger than that for h data that did not pass the self-sensitivity criterion for the 2014 adjustment and subsequently the NIM result was excluded from the 2017 adjustment.

The LNE Kibble balance project has published a result, performed in air, with a reported relative uncertainty of 0.057×10^{-6}. The NIST Kibble balance project produced a result with a relative uncertainty of 0.013×10^{-6} on the new NIST-4 system. Masses from 0.5 kg to 2 kg and velocities from 0.5 mm/s to 2 mm/s were evaluated. The NRC Kibble balance project produced a result with a relative uncertainty of 0.0091×10^{-6}. The NRC result was the summary of seven determinations using three different nominal masses over a time period of three years. The LNE, NIST and NRC Kibble balance results were included in the CODATA 2017 Special Adjustment.

Fujii presented document TGFC/17-06 outlining the status of the XRCD determinations of the Avogadro constant determinations. There have been two new results in 2017.

The first labelled NMIJ-17 is a re-evaluation of the S5c crystal sphere for the CCM pilot study. It involves new diameter, surface and mass evaluations by NMIJ and has a relative uncertainty of 0.024×10^{-6}.

The second is labelled IAC-17 and is based on PTB's new enriched crystal. While IAC-17 has a relative uncertainty of 0.012×10^{-6} it is $\sim 0.029\times10^{-6}$ higher than the CODATA-17, NMIJ-17 and NRC-17 results. As described in TGFC/17-06, the cause of the discrepancy is being pursued but is not yet obvious. There were discussions about the different results of the two crystals focusing on surfaces layer thickness, carbon impurities and the relative lattice spacing measurements.

Quinn expressed a concern about the application of the silicon lattice spacing result; specifically that the temperature of the 1 kg sphere and the temperature of the blades in the d_{220} experiment must be the same. Enrico Massa explained that there is a paper explaining the experimental verification of the temperature difference in the two experiments.

There were also discussions about the correlations between the four Avogadro results and about an Avogadro consensus value. The Task Group was informed that this was being prepared by the IAC but that the publication was not available in time for the Special Adjustment or this meeting.

- **Molar gas constant *R* and Boltzmann constant *k***

Fischer presented document TGFC/17-07 describing the status of the Boltzmann determinations. There are new Boltzmann acoustic gas thermometry (AGT) results from INRiM, LNE, NPL UniVal+CEM, and NIST/NIM. There is a dielectric constant gas thermometry (DCGT) result from PTB and a refractive index gas thermometry (RIGT) result from NIST. As well, there are three Johnson noise thermometry results from NIM/NIST, NIST and NMIJ. The results are quite consistent and satisfy the CCT's requirements for relative uncertainty and different methods.

Newell informed the Task group that a letter, TGFC/17-08, had been received from VNIIFTRI about an acoustic gas thermometry result that had been accepted for publication in a Russian journal (in Russian) before the Special adjustment deadline. However, neither the Task Group members nor the general membership of the CCT had knowledge of the paper's existence until after the special adjustment had been refereed and accepted for publication.

After considerations, discussions, and consultations with a number of CCT members, it was decided to not include this result into the special adjustment analysis. It was also determined that inclusion of the result would have resulted in a negligible change in the final numerical result.

Fine-structure constant α

Mohr and Nez discussed the status of the fine structure constant. While progress continues there are no new experimental results or substantial improvements in the theory.

- **Other data**

No other data was introduced.

b. Final Analysis

Newell summarized the final analysis of the 2017 special adjustment with document TGFC/17-09. The plots, statistics and uncertainties of the Planck and Avogadro constants, and the Boltzmann constant were presented. The recommended Planck constant value has a relative uncertainty of 6×10^{-9} but the data set is somewhat inconsistent. Expansion to 10×10^{-9} reduces the normalized residuals to acceptable levels. Of course this is also the case for the Avogadro constant. The recommended Boltzmann constant value has a relative uncertainty of 3.7×10^{-7} and did not require any expansion for consistency. Finally, the elementary charge has a relative uncertainty of 5.1×10^{-9}. The adjusted values and relative standard uncertainties of h, e, k and N_A are also listed in TGFC/17-02 and TGFC/17-03 as well as plots of the input data sets.

The final recommend values for the redefinition of the SI are listed in TGFC/17-02 and TGFC/17-03. The number of digits for each were selected to keep the exact values of the international prototype of the kilogram m (K) = 1 kg, the triple point of water T_{TPW} = 273.16 K, the molar mass of carbon-12, M (^{12}C) = 0.012 kg mol^{-1} and the vacuum magnetic permeability $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}.

On the subject of SI redefinition Taylor presented TGFC/17-04. It compared the values and uncertainties of the new and old SI base units, as well as 22 special units. Steele commented that the list would be useful for the CCU meeting the next day. It illustrates that the changes are quite robust.

c. **Publication**s

Concerning the publication of 2017 papers, the summary paper, TGFC/17-02, was submitted on August 2 and is accepted for publication in Metrologia. The CIPM has requested a delay of formal publication until after the CCU and CIPM meeting in 2018 and this is being done.

The more detailed document, TGFC/17-03, is in the process of being submitted but has not been refereed at the time of this meeting.

4 Update of new or expected results for the 2018 CODATA adjustment of the fundamental constants

a. Gravitational constant G

Schlamminger discussed the status of the Newtonian gravitational constant projects. He indicated that both NIST and Hurst should have new results in 2018. He also indicated that Faller has made a small correction to his result.

b. Fine-structure constant α

There was little discussion on this topic. See 4 a. A new h/m result is expected from Berkley but they have been delayed several times in the past. Nez indicated that there may be a new h/m result from the LKB. There is also a new bound state g factor experiment with three electron ions, but the associated calculations are difficult and without an expected completion date. Hessels has a helium fine structure determination but its uncertainty is not competitive.

c. Rydberg constant R_∞

Since 2014 there are only small changes in the theory affecting the Rydberg value and these are detailed in TGFC/17-03, page 3.

A new frequency result has been added, the $1S_{1/2} - 2S_{1/2}$ transition measured at MPQ Garching. Nez discussed a $1S$-$3S$ LKB experiment done at the LKB. It is done at room temperature but not yet published. It agrees with the previous hydrogen results. Taylor talked about the $2S$-$4P$ experiment at MPQ which is finished but also not yet published. It agrees with the muonic hydrogen results but its uncertainty is a bit large. It looks that new hydrogen results are not conclusive at the moment.

5 Other topics?

Proton radius r_p:

i. muonic hydrogen and deuterium

Newell reviewed the Task Group's approach to dealing with the proton radius problem. The TGFC will have to return to this problem and decide how it will proceed with the 2018 LSA.

In the meantime the discrepancies associated with the proton charge radius continue but have become better defined. Experiments have been repeated, auxiliary evidence has been incorporated and theories has been rechecked

and in some cases expanded. The evidence more clearly suggests that the muonic hydrogen and related results are valid. Under these circumstances it now seems that the Task Group will have to incorporate these results into the 2018 LSA and deal with the associated shifts in values and changes in relative uncertainties.

ii. e-p scattering

b. Relative atomic masses $A_r(X)$

Huang of the AMDC discussed the 2016 Atomic Mass Evaluation, document TGFC/17-10, which reviews some 3400 nuclides. There was a short discussion concerning the ^{3}He mass discrepancy of $\sim 3\sigma$ and the proton mass measurement from Germany.

The next AME is expected in 2020 or 2021.

Taylor asked if there was any insight into the proton mass discrepancy but there was no clear explanation. Karshenboim suggested having a session of mass spectroscopy at a future conference.

c. Other data

Pachucki discussed improved *g* factor calculations of Czarnecki from University of Edmonton (Canada) and possibility of more accurate calculations of transition freqencies in helium. Karshenboim commented on the possibility of improved helium transition calculations.

6 Task Group administration

a. Upcoming workshops

Surzhykov described the Heraeus Workshop scheduled for 13-18 May 2018. It is entitled 'Fundamental Constants: Basic Physics and Units'. See TGFC/17-11.

Karshenboim described PSAS'2018 – the International Conference on Precision Physics of Simple Atomic Systems. It is being held 14-18 May 2018.

b. Membership

Helen Margolis, who joined the Task Group in 2016 but was not at the 2016 meeting in Ottawa, was welcomed.

Two new Task Group members were announced. Jifeng Qu of NIM is an experimentalist and involved with the Johnson noise thermometry work at NIM and NIST. Andrey Surzhykov of PTB is a theoretician involved with quantum theory of atomic and mesoscopic systems.

Krzysztof Pachuki has accepted the vice chairmanship of the TGFC committee, replacing Barry Wood.

8 Date and location of the next Task Group meeting

The next Task Group meeting will be held just ***before*** CPEM 2018 on July 7, 2018 in Paris France.

9 Adjournment

The meeting was adjourned surprising early, at 13:00.

DRAFT AGENDA

CODATA Task Group on Fundamental Constants

9:30 a.m. Monday, 4 September 2017

BIPM

1. **Opening of the meeting and introductions**
2. **Review of the agenda**
3. **Review of the report of the Task Group meeting held on Saturday, 16 July 2016, Ottawa, Canada**
4. **The CODATA 2017 Special Adjustment of h, e, k, and N_A**
    a. **Relevant input data accepted for publication by 1 July, 2017**
        - **Planck constant h and Avogadro constant N_A**
        - **Molar gas constant R and Boltzmann constant k**
        - **Fine-structure constant α**
        - **Other data**
    b. **Final Analysis**
    c. **Publications**
5. **Update of new or expected results for the 2018 CODATA adjustment of the fundamental constants**
    a. **Gravitational constant G**
    b. **Fine-structure constant α**
    c. **Rydberg constant R_∞**
    d. **Proton radius r_p:**
        - **muonic hydrogen and deuterium**
        - **e-p scattering**
    e. **Relative atomic masses $A_r(X)$**
    f. **Other data**
6. **Other topics?**
7. **Task Group administration**
    a. **Upcoming workshops to endorse**
    b. **membership**
8. **Date and location of the next Task Group meeting**
9. **Adjournment**