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

9:30 am Monday, 10 June 2013
BIPM, BIPM, Sèvres, France
Prepared by B. Wood, National Research Council

The meeting was held at the BIPM in Sèvres. In attendance were the following members of the Task Group on Fundamental Constants: David Newell (chair), Barry Wood (vice chair), Franco Cabiati, Joachim Fischer, Ken Fujii, Savely Karshenboim, Peter Mohr, François Nez, Krzysztof Pachucki, Terry Quinn, Barry Taylor, Claudine Thomas (BIPM Liaison).

Present as observers were: Martin Milton (BIPM Director), Richard Davis, Michael Stock, Jifeng Qu, Ian Mills, Ambler Thompson, Host Bettin, Nadine de Courtenay, Fabien Gregis and François Biraden.

The follwing sent their regrets: Estefania de Mirandés, Zhang Zhonghua, Nick Fletcher, François Piquemal, Alain Picard.

The agenda of the meeting is included as the last page of this report, and the following summary is numbered according to the corresponding agenda item.

1. The meeting opened at 9:30 and introductions were made.

2. The meeting agenda was reviewed and accepted.

3. The report of the Task Group meeting held on Saturday, 7 July 2012, at the Gaylord National Resort, Washington DC was reviewed and accepted.

4. The RMP and JPCRD publications of the 2010 LSA were discussed. There have been several difficulties with the proofs from the JCPRD and several iterations have been required. The JCPRD publication now includes a list of tables and figures. Quinn asked for details about the distribution of this publication. It was recommended that notification of the RMP\JPCRD publications be sent to each of the Consultative Conmmittees and members of the CIPM.

5. Updates of new or expected results concerning:

   a. Rydberg constant, muonic hydrogen, proton radius

   Krzysztof Pachucki made a presentation about the 'proton charge radius puzzle' [Doc TGFC/13-04]. He began by reviewing the ensemble of $^{1}H$ and $^{2}H$ spectrum data, the electron-proton scattering results and finally the results from muonic hydrogen. He went on to describe what has transpired in the three years since the TGFC took the decision to not include the the muonic hydrogen result in the 2010 LSA analysis of the proton charge radius and the Rydberg. Since then a second

transition in muonic hydrogen has been measured ($2S_{1/2}(F = 0) – 2P_{3/2}(F = 1)$) that is consistent with the previous muonic hydrogen transition measurement which are both 0.3 meV discrepant from the prediction using the proton charge radius from CODATA 2010.

Pachucki listed four possible sources of this discrepancy arising from theory;

- a mistake in e - $^1$H calculations: all corrections have been calculated independently by at least two groups, uncertainty in the two-loop correction enters at 1 kHz level for 1S state, but this discrepancy corresponds to about 100 kHz
- missing QED correction
- mistake in μ - $^1$H: QED theory is quite simple, dominated by nonrelativistic vacuum polarization, everything has been checked and verified
- significant underestimation of the proton polarizability

He also listed two possible sources of this discrepancy arising from experiment;

- the determination of $r_p$ from e - p scattering data requires extrapolation to $q^2 = 0$, subject of systematic uncertainties
- 2S – nS, D measurements (mostly from one laboratory, LKB Paris), not confirmed by independent and equally accurate measurements

He then listed four avenues of investigation that might resolve the discrepancy.

- $\mu$ $^4$He, $\mu$ $^3$He, $\mu$ D
- determine $R_\infty$ by another accurate measurement in
    - 2S-4P in *H* (Garching, under way)
    - 1S-3S (Garching, planned)
    - 1S-2S in $He^+$ (K. Eikema, in preparation)
- determine $r_p$ from 2S - 2P transition in $^1$H: (E. Hessels)
- $\mu$ - p elastic scattering (Arrington et al.)

He also speculated that the problem may involve the internal structure of the proton. The proton charge radius is an extraploation to zero and perhaps this extrapolation is subject to systematic uncertainties. In his opinion the best hope to study the effect was to examine the 1S-2S in $He^+$ work.

S. Karshenboim stated that the electron-proton scattering data are not convincing.

Mohr felt that studies of the Rydberg constant measured in high states might also be fruitful.

Karshenboim stated that there are other experiments in development but that they may not be definitive very soon.

Nez indicated that a 1S-3S experiement is planned at the LKB in a year.

So in summary, both the associated theories and the experiments have been carefully reviewed and these reviews are internally consistent. A consensus is developing that the theory is sound and that it has been sufficently scrutinized to be trusted. The problem remains that the discrepency of the results can not be explained within the standard model. So either there is something wrong with the theory and experiments that have been reviewed by many scientists or we face new physics.

Wood asked Pachucki how he would vote today about inclusion of the muonic hydrogen data into the Rydberg analysis. Pachucki replied that he would now not vote to 'ignore' this result.

Newell reminded the task group that they were facing a difficult decision and hoped that members would consider it before the next meeting in 2014.

b. Alpha

Nez reviewed the most recent alpha determinations from Harvard, Berkley and LKB. At present the uncertainty of the g-2 experiment is about one half the uncertainty of atomic recoil results. Kinoshita's 2012 QED calculations of the $10^{th}$ order values are now complete. Unfortunately, there is no news of the Harvard g-2 experiment. Nez mentioned Müller's experiment using an atomic recoil experiment but with an optical frequency comb to self-reference a Ramsey-Bordé atom interferometer and synchronize an oscillator to a subharmonic of the Compton frequency.

Nez then described the LKB atomic recoil experiments and reiterated that two photon transition experiments yield precise momentum transfer. He explained that the Gouy phase shift uncertainty is being reduced with more optical power and a larger beam diameter.

Pachucki commented that the recoil measurement is essentially free of theoretical modeling and calculation.

Karshenboim reiterated that the g-2 and recoil experiemnts are complementary.

Taylor discussed the change in Kinochita's $10^{th}$ order QED calculations. These calculations have improved vacuum polization corrections; however, the result is a shift in the fine structure value. This comment was followed by various other comments about the difficulty of assessing their uncertainties.

c. $R$ and $k$

Fischer made a presentaion about recent Boltzmann determinations [TGFC/13-06] and focussed on the recent NPL and LNE-CNAM discrepancy in acoustic gas thermometry (AGT) experiements. The experimenters feel that dimentional uncertainties are unlikely to be the cause of the discrepancy and they now suspect

differences in the molar mass of the gases used. LNE is repeating some measurements using argon gas from NPL.

An AGT determination from a NIM-NIST collaboration has a claimed uncertainty of 7.9 ppm. It uses a cylindrical cell with end plate corrections but with different cell lengths.

The PTB dielectric constant gas thermometry (DCGT) experiment is operating at about 2 ppm. The compresability of the capacitor is a major problem and to evalute this effect a smaller cylinder system is being calibrated against larger cylinder system.

U of Paris-LNE expertiment of Doppler broadening thermometry (DBT) has achieved about 50 ppm. Modeling of the absorption line profile is still the major limitation of this technique.

Johnson Noise thermomerty (JNT) is being pursued by NIST/MSL, NIM, NMIJ. The best result to date is from NIST at 12 ppm with a possible improvement to 5 ppm.

A discussion followed about the state of the Boltzmann data set. Fischer discussed the correlation problem between the AGT results. Milton commented that Petri's original argon is now all gone so they will use the NPL argon as a test.

Fujii asked if NPL is using a microwave determination of the diameter their cell and Fischer responed yes as well as piconometry. Fischer went on to outline that the first condition of the CCT Recommendation T2 has been met but that the second condition has not.

d. Planck constant $h$ and $N_A$

Wood reviewed watt balance results by referring first to 'Report on the present status of some watt balances' by E. De Mirandés [TGFC/12-07] and briefly discussing the status or each watt balance project. Since there have been no new results in the last year he then focused on the two projects that were predicting to have a Planck constant determination within the next year [TGFC/13-07].

He explained modifications and improvements of the NRC watt balance and predicted a result with an uncertainty < 35 ppb.

Wood then described that NIST project including development of NIST 4 and a final measurment campaign on NIST 3. Results are expected to be revealed in June 2013.

Bettin of PTB presented the 'International Determination of the Avogadro Constant' [TGFC/13-08] and in particular discussed PTB's intent to complete all of the

measurements on newly enriched $^{28}Si$. The new silicon crystals are now grown and preliminary analysis is beginning.

Mills asked about the impurity analysis but it seemed that the analysis had not been completed.

Bettin also presented information about the EMRP project kNOW, the CCM working group WGR-kg and the CCM's recommendation G1 about Preconditions for a new kg definition. Karshenboim commented that such projects and recommendations were the work of the metrology community but felt that this was not appropiate for consideration by the TGFC.

e. Gravitational constant

Quinn talked about the only new G result since the last meeting; his own. A discussion followed about the correlation between the two BIPM results. Quinn commented that almost everything has been changed. The 2001 result had a torsion strip on top and there was no coordinate measurement machine (CMM). The same test masses have been reused but a slice of the masses has been removed in the new experiment. As well the servo control has been rebuilt.

The 2013 result has the torsion strip on a gimble; a CCM is intergal to the experiment and a new auto collimator used. The same vacuum vessel is used but importantly the moment of inertia is measured instead of just be calculated. Quinn felt that the correlation was almost zero. The publication should be available soon.

f. Others

An $m_e/m_p$ experiment is expected but not yet published. It should appear in Nature and is proported to have a 15 time improvement in uncertainty.

The LKB expects to have a new 1S-3S result that should have an impact on alpha.

6. General discussions about

a. Alternative analysis techniques

Cabiati made a presentaion about a statistical guideline to the approach of incorporating scatter into the weighted mean method of analyzing fundamental constant data. In this approach an additional term is included for the scatter. The first senario had one term added to all data. The second senerio had individual terms included for every datum.

Cabiati then showed some applications to subsets of data from the 2010 LSA and considered four cases and presented several models. A discussion followed with several questions. Wood asked Cabiati which senario he endorsed and Cabiati replied that a decision was not obvious. Newell pointed out that the case of the Boltzmann constant indicated a 2.9 ppm scatter which is much larger than has been indicated in the 2010 LSA.

Karshenboim commented on consistency estimates of the model and asked Cabiati about which aggerate estimate he favored. Cabiati endorsed the approach of individual expansion factors of the weighted mean.

7. Other topics

   a. Timeline for 2014 adjustment and adoption of new SI

      Quinn reminded the group about document [TGFC/13-02] that outilnes the role of the TGFC in the proposed redefinition of the SI. This document had been circulted earlier and there were few comments.

      Milton outlined the CCM's roadmap on redefinition of the SI and pointed out that the document is still a draft version.

   b. Official communication between CIPM and CODATA

      Newell explained the relationship of the TGFC and the CCU through which it communicates to the CIPM.

8. Task Group administration

   ICSU has reviewed CODATA and as part of that process the TGFC has also been reviewed.

9. The Date and location of the next Task Group meeting has been set as Saturday 30 August 2014, Rio de Janeiro, Brazil the day after CPEM 2014.

10. The meeting was adjourned at approximately 16:00.

# DRAFT AGENDA

## CODATA Task Group on Fundamental Constants

## 9:30 am Monday, 10 June 2013

## 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, 7 July 2012, at the Gaylord National Resort, Washington DC
4. Discussion of the RMP/JPCRD publication of the 2010 LSA
5. Update of new or expected results concerning
    a. Rydberg constant, muonic hydrogen, proton radius
    b. Alpha
    c. $R$ and $k$
    d. Planck constant $h$ and $N_A$
    e. Gravitational constant
    f. Others
6. General discussions about
    a. Alternative analysis techniques
7. Other topics
    a. Timeline for 2014 adjustment and adoption of new SI
    b. Official communication between CIPM and CODATA
8. Task Group administration
9. Date and location of the next Task Group meeting
10. Adjournment