Bureau International des Poids et Mesures

Consultative Committee for Mass and Related Quantities (CCM)

Report of the 10th meeting
(23 March 2007)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Bureau	Organisation
international	intergouvernementale
des poids	de la Convention
et mesures	du Mètre

Note:

Following a decision made by the International Committee for Weights and Measures at its 92nd meeting in October 2003, reports of meetings of Consultative Committees will henceforth be published only on the BIPM website in the form presented here.

Full bilingual printed versions in French and English will no longer appear.

A.J. Wallard,
Director BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR MASS AND RELATED QUANTITIES

as of 23 March 2007

President

Dr M. Tanaka, member of the International Committee for Weights and Measures, National Metrology Institute of Japan, AIST, Tsukuba.

Executive Secretary

Dr R.S. Davis, International Bureau of Weights and Measures [BIPM], Sèvres.

Members

Central Office of Measures/Glówny Urzad Miar [GUM], Warsaw.

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

Conservatoire National des Arts et Métiers/Institut National de Métrologie [LNE-INM], La Plaine-Saint-Denis.

CSIR – National Measurement Laboratory [CSIR-NML], Pretoria.

D.I. Mendeleyev Institute for Metrology [VNIIM], Rostekhregulirovaniye of Russia, St Petersburg.

Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

Korea Research Institute of Standards and Science [KRISS], Daejeon.

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Gaithersburg.

National Measurement Institute of Australia [NMIA], Lindfield.

National Metrology Institute of Japan, AIST [NMIJ/AIST], Tsukuba.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC-INMS], Ottawa.

Nederlands Meetinstituut, Van Swinden Laboratorium [NMi VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Slovak Institute of Metrology/Slovenský Metrologický Ústav [SMU], Bratislava.

Swiss Federal Office of Metrology [METAS], Bern-Wabern.

Technical Research Institute of Sweden [SP], Borås.

The Director of the International Bureau of Weights and Measures [BIPM], Sèvres.

Observers

National Metrology Institute of Turkey/TÜBITAK Ulusal Metroloji Enstitüsü [UME], Gebze-Kocaeli.

National Physical Laboratory of India [NPLI], New Delhi.

1 OPENING OF THE MEETING; APPROVAL OF THE AGENDA; APPOINTMENT OF A RAPPORTEUR

The tenth meeting of the Consultative Committee for Mass and Related Quantities (CCM)* was held at the International Bureau of Weights and Measures (BIPM), at Sèvres, on 23 March 2007.

The following were present: H. Baumann (METAS), W. Bich (INRIM), N. Bignell (NMIA), J.W. Chung (KRISS), S. Davidson (NPL), N.G. Domostroeva (VNIIM), H. Durlik (GUM), D. Elkington (NPL), P. Farár (SMU), K. Fujii (NMIJ/AIST), M. Gläser (PTB), A. Gosset (LNE), Z.J. Jabbour (NIST), C. Jacques (NRC-INMS), Y.A. Kiselev (VNIIM), M. Lecollinet (LNE-INM), A. Ooiwa (NMIJ/AIST), P. Pinot (LNE-INM), P. Richard (METAS), J.A. Robles Carbonell (CEM), R. Schwartz (PTB), A.G. Steele (NRC-INMS), M. Tanaka (President of the CCM), I. van Andel (NMi VSL), A.J. Wallard (Director of the BIPM), S.Y. Woo (KRISS), Y. Zhang (NIM).

Observers: A.K. Bandyopadhyay (NPLI), S.T. Yalçin (UME).

Invited: P. Becker (PTB), I.-M. Choi (KRISS), K. Jousten (PTB), C.M. Sutton (MSL), J. Valdés (INTI, CIPM member), E.R. Williams (NIST).

Also present: T.J. Quinn (Director Emeritus of the BIPM); P. Barat, R.S. Davis (Executive Secretary of the CCM), H. Fang, C. Goyon-Taillade, A. Picard, C. Thomas (Coordinator of the KCDB) (BIPM).

Excused: L.O. Becerra (CENAM), L.R. Pendrill (SP), B. van der Merwe (CSIR-NML).

Dr M. Tanaka, President of the CCM, opened the meeting at 9.00 am and welcomed the delegates.

The agenda was approved.

Dr W. Bich (INRIM) was designated as rapporteur.

The attendees then introduced themselves.

2 REPORT OF THE CCM *AD-HOC* WORKING GROUP ON CHANGES TO THE SI

Dr P. Richard, Chairman of the CCM *Ad-hoc* Working Group on changes to the SI (CCM AHWGSI**), reported on the WG activity (document CCM/07-06). He first recalled its terms of reference and present membership, then summarized the report of its first meeting, held

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* For the list of acronyms, click here.

** In anticipation of the discussion under item 6 below, the acronym CCM WGSI kg replaces CCM AHWGSI in all subsequent references to this WG.

in Turin on 9 July 2006, focusing on the WG views concerning the Recommendation G 1 (2005) of the CCM. According to the working group, the conditions, mentioned in that Recommendation, to be met before the kilogram is re-defined in terms of a fixed value of a fundamental constant are to be read as follows: the generic "[that] there are no significant unresolved discrepancies between results from independent experiments" means that agreement should be at the 95 % level of confidence. The second condition, "[that] the relative standard uncertainty of the best realization of the definition of the kilogram does not exceed two parts in 10^8 at the level of one kilogram" means that at least one experiment should have a relative standard uncertainty no larger than 2×10^{-8}. As concerns the third condition, "a sufficient number of independent experiments" is interpreted as "three", among which at least one watt balance and one Avogadro experiment.

Among other activities of the working group, Dr Richard mentioned a presentation given in January 2007 to the CCEM WGSI by Dr Davis, member of the working group.

Dr Tanaka commented on the possible need to relax the requirements concerning the uncertainty with which the future definition should be realized.

3 PRESENT STATE OF AVOGADRO AND WATT BALANCE EXPERIMENTS AND PROSPECTS UNTIL 2010

Dr Becker (PTB and International Avogadro Coordination, IAC), presented the International Avogadro project (document CCM/07-07). Activity on natural silicon ended in 2003, since it was deemed that the anticipated relative uncertainty of 2×10^{-8} could hardly be reached, due mainly to the uncertainty in the estimation of the molar mass of silicon. A parallel activity had been started in 2001 concerning the feasibility of carrying out the experiment using highly-enriched ^{28}Si obtained by isotopic enrichment. With a highly-enriched crystal, the influence of the molar mass correction, suspected to be a main error source, would be minimized. This activity was formalized in a contract between eight partners operating within the CCM and under control of the CIPM. In 2003 a contract was signed with the Russian Atom Agency for the production of a 5 kg poly-crystal ingot of enriched ^{28}Si.

Dr Becker then described the structure of job sharing between the partners, and the present situation of the different tasks, such as manufacturing of the spheres and measurements of mass, volume, lattice parameter, molar mass, etc. Concerning job sharing, he reported that one of the partners, the NPL, has left IAC and another, the NIST, will leave during 2007. As regards the present status of the project, he explained that a rod of 6 kg of polycrystal ^{28}Si was obtained in 2006 and that the monocrystal is being grown at the Institut für Kristallzüchtung (IKZ) in Berlin. Present studies concern the surface oxide layer. One of the options under investigation is to grow a controlled layer, either thermally or chemically. According to the agreed timetable, a final result is expected within 2009, in time for the 2010 CODATA Adjustment of fundamental constants.

Subsequently Dr Williams (NIST) gave a presentation on the experiments under way aimed at determining the value of the Planck constant h by means of a watt balance (document

CCM/07-08). The first experiment to be started had been that of the NPL. This experiment will be discontinued in Spring 2007, followed by the publication of final results.

He presented the most recent evolution of the NIST experiment with the present summary of uncertainties and the most recent results. The scatter of results over one year compares to the 100-years instability of Pt-Ir kilograms. (The NIST result has attained a relative standard uncertainty of 36×10^{-9}, as mentioned during the discussion of Item 4.) He reassured the CCM that NIST intends to fund the experiment into the future.

He then reviewed other existing experimental setups (BIPM, LNE, METAS), showing the main design features and bringing into light their respective merits and challenges.

He stated that NIM, China, is funding a new watt balance experiment, and that other NMIs, namely those of Finland, Korea, Mexico, New Zealand and Russia are considering activities in the field.

Dr Williams' presentation stimulated a discussion and many comments. Dr Elkington pointed out that the NPL intends to present results as soon as possible and explained the reasons why the NPL decided to discontinue the watt experiment. These are due mainly to the difficulty in continuously running the experiment. Dr Bignell wondered whether it is appropriate to take the mean of a long run and its standard deviation as an estimate of the Planck constant, due to possible correlations in the data due, perhaps, to the presence of $1/f$ noise.

Dr Quinn commented on the comparison between the one-year scatter and the 100-years instability of Pt-Ir kilograms, remarking that a component should be added to the latter, accounting for the unknown instability of the international prototype itself.

Dr Tanaka questioned Dr Williams about the noise spectrum of the NIST's result series. In response, it was commented that it might look reasonably Gaussian in the short term, but in the long run it would not be so.

Dr Davis commented that, in any case, a Gaussian distribution does not imply that the data noise distribution is white.

Dr Steele spoke in favour of a joint cooperation, involving collegial help among institutes. Various members of the CCM pointed out that the yearly series of international meetings involving watt balance research groups went some way toward ensuring such cooperation.

4 PRESENT PROPOSALS FOR REDEFINING THE KILOGRAM

Dr Tanaka recalled the working documents and invited Dr Williams to present his proposals for changes to the SI. During his presentation (document CCM/07-09), he focused on a proposal based on seven constants having fixed values, to be compared to the present SI in which three constants are fixed, namely: the speed of light in vacuum, c_0, the ground state hyperfine splitting transition frequency of the caesium 133 atom, $\Delta\nu(^{133}\mathrm{Cs})_{\mathrm{hfs}}$, and the spectral luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz, $K(\lambda_{555})$. The four constants floating in the present SI, and to be fixed according to the suggested changes, would be: the Planck constant h, the elementary charge e, the Boltzmann constant k and the Avogadro constant N_{A}. This would

implicitly define the units of mass, electricity (current, voltage or resistance), temperature and amount of substance, respectively.

Dr Williams defended the view according to which the time has come to proceed with the above-mentioned changes, once the existing discrepancies between the watt balance experiment and the Avogadro experiment are resolved. He commented that a system of units with uncertainty-free constants is better suited to foster new ideas.

Dr Tanaka thanked Dr Williams for his presentation. Dr Davis commented on the present correlations between CODATA adjusted values.

The President then invited Dr Gläser to review the proposed new definitions of the mass unit (document CCM/07-10). Starting from the present situation on the experimental values of the relevant constants N_A and h, Dr Gläser exposed the new definitions under discussion. These can be categorized as explicit-unit or explicit-constant definitions, according to whether they explicitly fix the value of a property of the unit, such as its equivalent energy or its de Broglie-Compton frequency, or the value of the relevant constant, the Planck constant h. He criticized the idea of de Broglie-Compton frequency applied to a macroscopic body, on the grounds that the watt balance experiment does not probe the wave nature of a macroscopic body. In addition, such concepts appear unphysical when applied to a macroscopic body. He also criticized the explicit-constant definition, claiming that the link between a macroscopic quantity as a 1 kg mass and the Planck constant, as established by the watt balance experiment, is highly indirect and artificial.

He then presented two additional definitions for the mass unit based on a) the rest mass of ^{12}C atoms and b) a fixed number of particles and the creation energy of such a particle, respectively. Definition a) fixes the value of the Avogadro constant and definition b) the value of the Planck constant (implicitly). He defended the merits of these definitions, said to be more intuitive to understand and more realistic from a physical viewpoint. In these proposals, to avoid inconsistencies it is necessary that the mole be defined independent of the kilogram. Thus the mole would simply be the name given to a specified number of entities and, thereby, have dimension unity.

He then discussed the impact of the different definitions (i.e., of fixing this or that constant, or combination of constants) on the electrical units of the future SI and on the other constants.

In the subsequent discussion, Dr Williams confirmed that the present uncertainty of the NIST watt balance experiment is 36×10^{-9}.

Dr Valdés was pleased to see that the CCM is considering the redefinition of the kilogram with a wide view over the entire SI. The CIPM has to consider the points of view of the different Consultative Committees. In this respect, the CCEM recommended that the values for h and e be fixed as soon as possible in order to unify the two existing systems for electrical units.

Concerning the proposals for a new definition of the kilogram, Dr Valdés was, in principle, in favour of those based on the mass of a number of specified particles. New ideas might enter into future consideration, with reference, for example, to specially designed nanoparticles, and not merely atoms, electrons or other elementary particles. He questioned how well the wavelength associated to an atom, or even to the electron, can be measured. He wondered whether it could be of benefit to consider ^{60}C buckyballs instead of single atoms of ^{12}C.

Dr Gläser replied that measurements of creation frequencies are routinely carried out in particle physics. Concerning ^{60}C buckyballs, both Dr Davis and Dr Gläser agreed that their vibration

spectra make them an inconvenient choice but, in any event, the CCU is probably a better forum for this debate.

Dr Quinn felt that in Dr Gläser's presentation a confusion was made between the definition of a unit and its realization. He defended the view according to which quantum Hall and Josephson effects are fully legitimate macro quantum effects.

Dr Steele spoke in favour of an easy-to-understand definition, linked to a well-known formula of physics. An example would be a definition based on the de Broglie-Compton wavelength, which is actually an easy concept to explain to students. For example, many high school students in Canada are asked to calculate the wavelength of a baseball (mass of about 150 g) and they have no trouble with this. Whether the result of the calculation has physical significance is a secondary issue.

According to Dr Bich, the choice of what to fix comes logically before that of the most appropriate definition. Furthermore, the two decisions are to some extent independent. As to the criteria to follow in the choice concerning which constants to fix, he said that consideration should be given also to minimization of the variance-covariance matrix of the adjusted constants.

Dr Williams said that his proposal to fix seven quantities can be viewed as a one-to-one mapping from the present SI to the future.

5 CONSEQUENCES (IF ANY) TO MASS METROLOGY OF A NEW KILOGRAM DEFINITION

- that meets the specifications laid out in the Recommendation of the 9th CCM,
- that fails to meet one or more of these specifications,
- that might not be based on the rest mass of an atom or sub-atomic particle.

Dr Tanaka invited Dr Davis to address this item (document CCM/07-11).

Dr Davis first recalled that the CCM must not only report to the CIPM but also to CCU in time for their next meetings (June 2007). This means that a report must be ready by the middle of May. He then reviewed the relevant Resolutions and Recommendations of CCEM, CCM, CIPM and CGPM, arriving finally at those of the CCM WGSI kg and of the corresponding CCEM WGSI.

He then summarized the most important issues concerning the redefinition of the kilogram with reference to the needs of the mass community. Many of these issues had already been addressed in Recommendation G 1 (2005) of the CCM, he therefore wondered whether the CCM would still agree with that recommendation or whether some of the conditions for a redefinition of the kilogram should be updated. Specifically, should the requirement about an uncertainty no larger than 2×10^{-8} in the realization of the new definition be kept or weakened? The same question applies to the requirement concerning the minimum number (currently three) of independent laboratories. In addition, is the CCM concerned with the choice of the definition or not? Should an international coordination be established under the BIPM in order to maintain a "virtual"

value of the kilogram, based on the different realization, in a way analogous to what is done for TAI.

Dr Steele suggested that an inter-Consultative Committee Working Group on the SI to be established.

Dr Thomas replied that the next June CCU meeting will accomplish the goal advocated by Dr Steele. Some fifteen scientists from the relevant Consultative Committees will be invited to attend the CCU meeting. Representatives of the CCM will be Dr Gläser, Dr Richard and Dr Davis.

6 PREPARATION OF CCM REPORT TO THE CIPM

Dr Davis re-proposed the issues in view of the preparation of a CCM report and the President Dr Tanaka asked to define the relevant actions. As a conclusion, it was decided that the CCM WGSI kg would prepare a draft report to be submitted for comments to the CCM by the end of April, and then to CCU and CIPM. To help the WGSI kg in its task, CCM Recommendation G 1 (2005) was reviewed. In the subsequent discussion:

- The requirement about an uncertainty no larger than 2×10^{-8} in the realization of the new definition was reaffirmed.
- It was decided that a reference value should be determined from a set of individual realizations, and the coordination of this should be given to the BIPM.
- The question was raised whether the WGSI kg should become permanent. The decision was affirmative. As a consequence, the membership would be updated according to normal procedures of working groups. A revision of the terms of reference was also foreseen.
- It was agreed that the CCM should not express an opinion concerning the choice of the definition, so long as it permits a suitable *mise en pratique* for realization at 1 kg.

The report of the WGSI kg was then reviewed and the specifications of Recommendation G 1 (2005). A preliminary draft of a report to the CCU and CIPM was presented for consideration by the WGSI kg. In it, further to the issues mentioned above, a request is made to the CCM WGAv to define conditions of suitability for Si artefacts as long-term mass standards. In addition, the CCM approved the establishment of a task group within the CCM Working Group on Mass Standards (WGM) to help BIPM establishing an uncertainty budget for their routine calibrations of national copies of the prototype. A second task group, also within the WGM, to coordinate common problems of weighing in vacuum and storage in inert atmospheres or vacuum. Dr Davis reported that the BIPM is committed to creating and maintaining a stable group of 1 kg artefacts, whose number and composition are still under consideration. The formation of both task groups will be left to the WGM.

7 SUMMARY REPORT OF CCM WG CHAIRPERSONS MEETING

Dr Sutton, Chairman of the CCM Working Group on CMCs, reported on the meeting of the working group chairs held on 22 March. During that meeting, each working group had reported on the status of its key comparisons and on the relevant strategic planning issues. A common issue had been the perceived need that the key comparisons be organized and carried out according to the agreed guidelines. A proposal was reported for a discussion forum to be established, also in order to facilitate the review of key comparisons. No need had been felt to update the existing methods concerning the review and the submission of revised CMCs. A guidance document is currently being prepared, with help from the different working groups, on the comparisons deemed necessary to support CMCs in the various technical areas of the CCM, and on related topics. As concerns the structure of working groups, it had been decided to merge the former Medium and High Pressure Working Groups in a new High Pressure Working Group, the choice of the border pressure between the two remaining working groups being left outstanding. The chair will be taken by Dr J.-C. Legras of LNE.

The meeting concluded and Dr Tanaka thanked everyone for their attendance.

Walter Bich, Rapporteur

April 2007

APPENDIX G 1.
WORKING DOCUMENTS SUBMITTED TO THE CCM AT ITS 10TH MEETING

Open working documents of the CCM can be obtained from the BIPM in their original version, or can be accessed on the BIPM website:

(http://www.bipm.org/cc/AllowedDocuments.jsp?cc=CCM).

Document CCM/	
07-01	Considerations on future redefinitions of the kilogram, the mole and other units, P. Becker *et al*., 14 pp. (*Metrologia*, 2007, **44**, 1-14) (restricted access)
07-02	Redefinition of the kilogram, ampere, kelvin and mole: a proposed approach to implementing CIPM Recommendation 1 (CI-2005), I.M. Mills, T.J Quinn, B.N. Taylor and E.R. Williams, 20 pp. (*Metrologia*, 2006, **43**, 227-246) (restricted access)
07-03	CCEM WGSI. — Documents 1 from CCEM Working Group on Changes to the SI (WGSI), dossier Zip.
07-04	CCEM WGSI. — Presentations made at the CCEM Working Group on Changes to the SI (WGSI), dossier Zip.
07-05	CCEM WGSI. —Draft Recommendation EM 1 (2007): Proposed changes to the SI, 2 pp. (restricted access)
07-06	CCM AHWGSI, METAS (Switerland). — Report of the CCM *Ad Hoc* Working Group on Changes to the SI (AHWGSI), P. Richard, 6 pp.
07-07	PTB (Germany). — Determination of the Avogadro constant: A contribution to the new definition of mass unit kg, P. Becker, 18 pp. (restricted access)
07-08	NIST (United States). — Status of watt balance experiments, E. Williams, 22 pp. (restricted access)
07-09	NIST (United States). — Proposed changes to the SI, their impact on fundamental constants and other SI units, E. Williams, 27 pp.
07-10	PTB (Germany). —New definitions of the kilogram and the mole – Discussion (revised), M. Gläser, 28 pp.
07-11	BIPM. —Report to the CIPM (June 2007) and to the CCU in time for its meeting on 11-12 June 2007 – Important points to consider, R. Davis, 13 pp. (restricted access)