Bureau International des Poids et Mesures

Consultative Committee for Units (CCU)

Report of the 21st meeting
(11-12 June 2013)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Note:

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

Full bilingual printed versions in French and English are no longer published.

M. Milton,
Director BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR UNITS

as of 11 June 2013

President

Prof. Ian M. Mills, Emeritus Professor of Chemistry, Department of Chemistry, University of Reading

Executive Secretary

C. Thomas, International Bureau of Weights and Measures [BIPM]

Members

Centro Español de Metrología [CEM], Madrid

Commission internationale de l'éclairage [CIE]

Committee on Data for Science and Technology [CODATA Task Group on Fundamental Constants]

Federal Agency on Technical Regulating and Metrology [Rosstandart], Moscow

International Astronomical Union [IAU]

International Commission on Radiation Units and Measurements [ICRU]

International Electrotechnical Commission [IEC]

International Federation of Clinical Chemistry and Laboratory Medicine [IFCC]

International Organization for Standardization [ISO]

International Organization of Legal Metrology [OIML]

International Union of Pure and Applied Chemistry [IUPAC]

International Union of Pure and Applied Physics [IUPAP]

National Institute of Metrology [NIM], Beijing

National Institute of Standards and Technology [NIST], Gaithersburg

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

National Physical Laboratory [NPL], Teddington

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

Prof. M. Himbert, personal member

T.J. Quinn CBE FRS, personal member

The Director of the International Bureau of Weights and Measures [BIPM], *ex officio* member

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

The twenty-first meeting of the Consultative Committee for Units (CCU) took place at the International Bureau of Weights and Measures (BIPM), Pavillon de Breteuil, Sèvres, from 11 to 12 June 2013.

The following were present: P. Blattner (CIE), N. Capitaine (Observatoire de Paris, IAU), G. Férard (IFCC), K. Fujii (NMIJ/AIST), P. Gérôme (IEC/TC25) M. Himbert (Académie des Technologies, Paris), S. Lea (NPL), L. Mari (IEC/TC1), H.G. Menzel (ICRU), M.J.T. Milton (Director of the BIPM), I.M. Mills FRS (President of the CCU, IUPAC), D.B. Newell (NIST, CODATA), P. Mohr (NIST), J. Obdržálek (IEC/TC25), M. Paul (CIE), L. Pendrill (ISO/TC12), J. Qu (NIM), T.J. Quinn FRS CBE (Director Emeritus of the BIPM), Ph. Richard (OIML, METAS), J. Schwob (ISO/TC12), A. Thompson (NIST), J. Stenger (PTB), L. Vitushkin (VNIIM), C. Williams (NIST), B. Wood (NRC, CODATA).

CIPM member: L. Érard.

Invited guests: F. Arias (BIPM), H. Bettin (PTB), W. Bich (INRIM), Ch. Bordé (Académie des Sciences, Paris), R.S. Davis (BIPM), J. Fischer (PTB), S. Karshenboim (MPQ, Germany), J. Kovalevsky (Honorary member of the CIPM), J.M. Los Arcos (BIPM), J.R. Miles (BIPM), S. Picard (BIPM), L. Robertsson (BIPM), M. Stock (BIPM), B.N. Taylor (NIST), R.I. Wielgosz (BIPM), J. Zwinkels (NRC).

Also present: C. Thomas (Executive Secretary of the CCU) from the BIPM.

Absent: sent apologies. E. De Mirandés (BIPM), W. Phillips (IUPAP/NIST), A. Picard (BIPM), E. Prieto (CEM).

The President opened the meeting with homage to Anders Thor, who passed away on 7 April 2012. Anders Thor had been for a long time a member of the CCU, in his capacity as Secretary first (1982-2009), and subsequently Chairman of ISO/T12, Quantities and Units. He was also Chairman of IEC/TC 25, Quantities and Units, since 1988, and the driving force behind the publication of the ISO/IEC 80000 Series of standards. Prof. Mills recalled his great human and professional qualities, and asked the Committee to obey a minute of silence in his memory.

The President then welcomed the attendees, and asked them to briefly introduce themselves.

M. Milton, Director of the BIPM, also welcomed the participants. He stated that, among the Consultative Committees involved in the changes to the SI, there is great expectation and attention towards the activity of the CCU. In addition, whereas all the other Committees had been asked to develop a document indicating their long-term strategy, this did not happen for the CCU, which demonstrates that its mission is clear and uncontroversial.

W. Bich, INRIM, was appointed as *Rapporteur*.

The Draft Agenda, dated 16 April 2013, was approved.

2. PRESIDENT'S REPORT

The President recalled the task of the CCU, that is, to advise the CIPM on issues concerning quantities and units. He then reported on his activity since the 20th meeting of the CCU in 2010. He attended the 99th and 100th CIPM meetings in 2010 and 2011, respectively, and the 24th meeting of the CGPM in 2011. There, he presented plans for the revision of the SI, which were strongly supported, as demonstrated by the unanimous vote on the adoption of Resolution 1 by the CGPM.

He also contributed, through various initiatives, to spread information on the intended revision of the SI. He gave a presentation at the Helmholtz Symposium 2012 held at the PTB on the occasion of its 125th anniversary. Another presentation was given in July 2012 at the Conference on Precision Electromagnetic Measurements, CPEM, Washington DC. He also gave lectures, some of which to non-specialist audiences, all successful.

He then recalled the essentials of the SI revision, based on seven definitional constants rather than on seven units. He also reminded the attendees of the page devoted to the new SI on the BIPM website and of the section concerning Frequently Asked Questions.

3. BRIEF REPORTS ON ACTIONS TAKEN SINCE THE 20TH MEETING OF THE CCU RELEVANT TO THE ADOPTION OF THE REVISED SI

3.2 Reports from the Consultative Committees

Ph. Richard, 5th President of the CCM (since October 2012), gave his presentation. He started with an overview of the Committee and its recent history, during which it underwent considerable changes, as reflected in the "Strategy 2013-2023" document, prepared by its relevant working group. The Committee structure was simplified, by reducing its working groups from fourteen to eleven, and further rationalization is envisaged. The working groups directly related to the kilogram are now two, WGR-kg and WGD-kg, dealing with its realization and its dissemination, respectively. Also criteria for membership of the Committee as well as of its working groups are being revised.

Ph. Richard then mentioned the *mise en pratique* of the definition of the kilogram, currently at its version 7.1. This important document was the main subject of a workshop held in November 2012 and was further discussed at the 14th CCM. The CCM President also informed that the topic will be the subject of a special issue of *Metrologia*, planned for 2016.

Another important initiative of the Committee is a comparison with the International Prototype of the Kilogram, IPK, initially proposed in 2010 in Recommendation G2, and further endorsed by the CIPM. One of the aims of the comparison is to establish, prior to the redefinition of the kilogram, a firm traceability to the IPK for the national standards of those laboratories which possess candidate primary realizations of the kilogram. A support group has been established, chaired by the BIPM Director. Among its tasks there are the choice of participants, the establishment of a protocol, and the development of a timeline.

Ph. Richard subsequently recalled the CCM Recommendation G1 (2013), commenting its main points and the conditions to be met before the redefinition of the kilogram can take place. He proposed a possible timeline for the redefinition, a draft roadmap framing the main steps (IPK comparison, approval of the *mise en pratique*, key comparison, solution of the discrepancies) in the more general framework of the SI revision. He commented on the many details that need to be dealt with before the redefinition can take place. This, according to the timeline, might happen in 2018.

Ph. Richard finally announced that the next CCM meeting will be held on 26-27 February 2015, having as its main tasks the approval of the *mise en pratique* and the analysis of the situation in the light of the timeline and compared with the conditions to be met. Initiatives will be undertaken to encourage members to be more active in the discussion.

P. Blattner (CIE) asked whether the *Metrologia* special issue would be entirely devoted to the *mise en pratique* of the definition of the kilogram, which was confirmed by J. Miles, Editor of the journal.

Prof. Mills commented on the good shape of the *mise en pratique*, and Ph. Richard and H. Bettin, the latter in his capacity as chair of the WGR-kg, confirmed that there is good convergence on the document and it will not be difficult to have it approved by the CCM in due course. Prof. Mills recalled that, although the responsibility for the *mises en pratique* of the definitions of the various units is to the involved Consultative Committees, it is desirable that the CCU be informed about their development in order to be able to transmit updated information to the CIPM.

M. Milton commented that the proposed roadmap is very complete. He mentioned two further, comparatively minor events: a technical workshop on watt balances, and a meeting of the support group for the calibration with the IPK. He would like the CCU to give his feedback on the roadmap. Finally, he remarked that the CCM roadmap is the only one he is aware of, whereas more of them should be prepared by other involved Committees, such as, for example, the CCEM.

T. Quinn, Director Emeritus of the BIPM, pointed out that almost all the events indicated in the roadmap are predictable with reasonable accuracy except the time at which the required consistency would be reached among the different estimates of the Planck constant h. He suggested that, should consistency be achieved earlier than anticipated in the roadmap, then the SI revision might also be promulgated earlier than in 2018. Ph. Richard replied that the roadmap looks realistic in this respect, although he agreed that the time of satisfactory consistency is not predictable. In any case, the timescale does not depend heavily on that time, being dominated by other processes, such as, for example, the comparison with the IPK and the key comparison mentioned in the Recommendation CCM G1 (2013). T. Quinn still was not persuaded. He was supported in this by Prof. Mills, who exhorted the CCM to adopt a flexible attitude in this respect.

B. Wood, NRC and CODATA, spoke for the CCEM, which met in March 2013 and discussed the SI revision. The Draft *mise en pratique* for the definition of the ampere was approved in 2009 by the CCEM, but may still be revised. The CCEM is ready and waiting for the SI revision to be adopted. There followed a discussion on consultation and education about the new SI within the community of electrical metrology. These actions are purposely progressing slowly in order to avoid them to be premature with respect to the date of adoption of the new SI. M. Stock, BIPM, pointed out that the new SI will imply some consequences to the electrical community which have not been sufficiently discussed yet, and which he would present later in more detail.

R. Wielgosz, Director of the BIPM Chemistry Department and Executive Secretary of the CCQM, communicated that the CCQM met in April 2013 and that since June 2012 the *mise en pratique* for the definition of the mole had been freely available for discussion on the open access of the CCQM

web page. They received a dozen comments, of which most are against the redefinition and few in favour of it. He mentioned a proposal by the PTB according to which the definition of the mole (as defined in the current SI) can be realized also by counting the atoms in a silicon sphere. As to the redefinition itself, the IUPAC supported it, but the discussion will continue at their 44th Congress in August 2013. He announced that a workshop on these topics is planned for April 2014. Prof. Mills expressed his appreciation for the workshop and his interest in being personally involved in the general discussion.

J. Zwinkels, NRC and chair of the CCPR working group on strategic planning, expressed her thanks for having been invited to attend this CCU meeting, and reported about the CCPR. They met in April 2013, after a workshop on SI units for photometry and radiometry organized by their Task Group 4 "SI". Three had been the main topics of the workshop, namely: the change of the base unit from candela to lumen, proposed by T. Quinn; the definition, measurement, implementation of photometric quantities, and the *mise en pratique* of the definition of candela; and the reformulation of the candela in terms of counting photons.

As to the change of the base unit from candela to lumen, which would imply a corresponding change of the base quantity for photometry from luminous intensity to luminous flux, J. Zwinkels summarized the exhaustive discussion held at the workshop, including contributions from the CIE, and the final decision (by consensus) that the candela be kept as base unit (and luminous intensity as base quantity) essentially because of its intrinsic geometrical features, which are deemed essentials for photometry. She then recalled the current definition, valid for photopic, scotopic and mesopic vision, although until recently there existed no agreed method of spectral weighting for mesopic vision. In 2010 CIE made a proposal (CIE 191:2010) which will allow writing a *mise en pratique* valid for the full dynamic range of human vision in the SI. Subsequent, intermediate steps were the establishment of a joint CCPR-CIE Technical Committee with the task of revising the basic document *Principles Governing Photometry* (available as a BIPM monograph), and the decision that CCPR WG-SP TG5 prepares a concise *mise en pratique* for the definition of the candela. It is anticipated that the two documents will be ready by the time of the next CCPR meeting in 2014. As to the structure of the latter Committee, two new task groups have been established, TG4-SI and TG7-Discussion forum on few-photon metrology. A position paper was also published concerning the evolution in the classical and quantum worlds for the candela.

The last topic in the agenda of the 2013 workshop was the possible reformulation of the candela in quantum terms, i.e., in terms of counted photons. After a discussion on advantages and disadvantages of the possible new formulation, it was decided that quantum nature of photon should be emphasized, by including the photon way in the *mise en pratique*.

As a last topic of her detailed report from CCPR, J. Zwinkels discussed the reformulation of the definition of the candela as written in the current Draft Chapter 2. The CCPR proposes a correction and a suggestion to express the value of the constant of luminous efficacy K_{cd} in terms of base units first, followed by the expression in terms of the derived units lumen and watt.

Prof. Ch. Bordé, Académie des Sciences, commented about the uncertainty of the number of photon due to phase uncertainty. M. Stock replied that this contribution should not play a role in the definition of the candela.

L. Érard, CIPM and President of the CCTF, reported that the CCTF had met in September 2012, the main outcomes being various recommendations concerning an update of the list of standard frequencies, the regular calculation and publication of "rapid UTC" (UTCr), the development of continental-scale optical fibre transmission of clock signals and others. Also the issue of the leap

second was discussed in connection with UTC and other time scales, as well as with other organizations involved, such as ITU.

L. Érard then presented a proposal from the CCTF Task group on the definition of the second, consisting of a better specification of the state of the Cs atom in the definition, namely, that it should be unperturbed. This was supported by various participants and accepted. A discussion started on the ambiguity of the definition, in that, according to S. Karshenboim, emission and absorption frequencies are slightly different. Prof. Bordé encouraged use of the Bohr frequency as an unequivocal term. S. Lea, NPL, commented that within the community of those working on caesium fountains there is awareness that the photon recoil shift should be treated as a systematic effect to be corrected for, since caesium fountains are now approaching the level of accuracy where this needs to be taken into account. Therefore, they implicitly understand the current definition of the SI second to refer to the Bohr frequency of the transition. W. Bich expressed the INRIM view, according to which it should be specified that the Cs atom should be "unperturbed by any external field …" (thus including blackbody radiation). In addition, he was in favour, as J. Stenger, of keeping the definition as simple as possible while changing the explanatory text. Prof. Mills concluded by reminding that there is still time for discussion before a definitive decision has to be taken.

L. Robertsson, Executive Secretary of the CCL, reported that the CCL had discussed the proposed new definition of the metre at its last meeting in 2012 and, although they are not fully satisfied with the wording, they understand its motivation and simply take note of the proposal.

J.M. Los Arcos, Director of the BIPM Ionizing Radiation Department and Executive Secretary of the CCRI, said that the CCRI is not directly involved in the actions for the new SI. However, he mentioned that the CCRI Strategy considers two emerging actions that concern a) the formulation of biologically-related quantities and b) nano-dosimetry studies focusing on the establishment of new radiation qualities and on the effectiveness of 3D/4D dose distributions in medical applications.

Finally, S. Picard, Executive Secretary of the CCAUV, reported that there is no feedback to the CCU from that Committee.

3.3 Report from the OIML

Ph. Richard, now in his capacity as OIML delegate, reported from this Organization. A first article, by R. Davis, on the impact on legal metrology of the new definition of the kilogram, appeared on the October 2011 *OIML Bulletin*. A second, by R. Schwartz *et al.*, followed in September 2012. As an outcome of discussions within the various Technical Committees, the OIML made a statement supporting Recommendation 1 of the 24th meeting of the CGPM, also encouraging strict adherence to the CCM recommendations in order to avoid potential impact on highest-level mass metrology. A similar statement came from CECIP, the European Association of Manufacturers of Weighing Instruments. Ph. Richard showed a diagram in which the mass changes of national prototypes over a century is compared with the 1998-2010 CODATA recommended values of the Planck constant and their uncertainties.

T. Quinn, supported by C. Williams, NIST, objected that the diagram is misleading, because it describes the current situation of mass metrology as fully satisfactory. It is not satisfactory because it hides part of the truth, and it should not be further circulated. In the diagram, mass changes are referred to the present definition of the kilogram, whose stability is unknown. This means that the slope of the reference line in the diagram is unknown, and might be very steep, due to the unknown changes in the mass of the reference. R. Davis agreed with the spirit of this comment but pointed out

that it is incorrect to say that the slope of the reference line with respect to fundamental constants is unknown. The slope is known, but only within wide limits presently imposed by a combination of the uncertainties of the best experimental determinations of the Planck constant and the time span over which such measurements have been available. He added that acknowledging this does not imply that the current situation in mass metrology is satisfactory.

S. Karshenboim wondered why there was no feedback from electrical legal metrology. C. Williams noted that the electrical community is, and has been, outside the SI since 1990. They should be happy with the revision of the SI. W. Bich explained that they have a comparatively minor weight in legal metrology. Prof. Mills re-stated the will of the CCU to redefine the SI units in terms of constants of nature. This was supported by R. Davis, who asserted that fixing the value of the Planck constant h will imply fixing the reference line in the diagram under discussion to be exactly horizontal with respect to the constants of nature, uncertainties then falling in a first instance on the initial mass calibrations of the international prototype and other artefact standards. Subsequent temporal changes, in micrograms per year, could in principle be inferred for artefact mass standards over the span of a given number of years provided the uncertainties of the mass calibrations are small enough to yield meaningful results.

3.4 Reports from other organizations and institutions, CIE, IEC, ICRU, IAU, IFCC, ISO, IUPAC, IUPAP, Académie des Sciences de Paris

P. Blattner, METAS and CIE delegate, provided some update on the CIE, its structure and organization. He mentioned some recent scientific publications, among which is the notable International Lighting Vocabulary, ILV, containing more than 1400 entries. He then recalled the 2007 agreement with the CIPM, highlighting some aspects relevant to the revision of the SI. He then specifically discussed the proposed reformulation of the candela, emphasizing the prominence given to the reference constant of luminous efficacy K_{cd}, and stating that the CIE supports the proposal, thus excluding a potential formulation in terms of photons. He commented that K_{cd} is close to the highest possible value for luminous efficacy under photopic conditions, but corresponding to the reference frequency of 540 THz, i.e., to green light, which is not of great practical use. He then discussed the luminous efficacy for various sources, especially in white light. He highlighted the spectral broad-band nature of photometry, and its link with radiometry. He outlined recent studies on new spectral luminous efficacy functions for non-standard conditions, such as mesopic or 10°, discussing also the efficacy dependence on the age of the observer. Some of these issues will be reflected in the update of the (already mentioned) basic document *Principles Governing Photometry* anticipated by mid 2014. Some new functions will be explicitly given, although this will not impact on the definition.

Prof. L. Mari reported for IEC/TC1, Terminology. He mentioned *Electropedia*, the World's online electrotechnical vocabulary, containing more than 20 000 entries.

Prof. J. Obdržálek, for IEC/TC25, Quantities and Units, said that they are monitoring the evolution of the new definitions of the base SI units. The results will be used for the regular maintenance and possible reformulation of the dual-logo ISO/IEC 80000 series “Quantities and Units”.

For ICRU, H.G. Menzel gave an overview of the recent activities, including the 2012 and 2013 annual meetings of the ICRU Commission, and publications, the most relevant to the CCU being Report 85a *Fundamental Quantities and Units for Ionizing Radiation* (2011), an update of ICRU 60. This Report was published under the responsibility of committee RC 00 on Fundamental Quantities

and Units. ICRU work is focused on medical applications in radiological diagnostics and radiation therapy, on radiation protection and on conceptual issues of dosimetry. In this framework sometimes the need is felt for new quantities, such as equi-effective dose in radiation therapy. In the subsequent discussion, B. Taylor, NIST, asked whether this would imply the need for introducing new units. Prof. Mills' feelings were that these are important issues that should be discussed in connection with the SI. M. Milton agreed, although he thought that the topic was beyond the scope of the meeting.

N. Capitaine reported that the IAU keeps closely informed about the developments concerning the revision of the SI. She also mentioned the new definition for the astronomical unit, to be discussed under Agenda item 11.

The IFCC delegate, Prof. G. Férard, informed that they are currently revising, jointly with IUPAC, the 1995 Silver Book "Compendium of Terminology and Nomenclature of Properties in Clinical Laboratory Sciences". He declared the interest of IFCC in the redefinition of the mole and in the related workshop announced by R. Wielgosz.

Prof. L. Pendrill, ISO TC12, mentioned the continuous effort to keep updated the 14 parts of the 80000 Series of standards on quantities and units. They are revising their business plan, and forming an editorial group. He welcomed an improved collaboration with other international metrology organizations. B. Taylor asked whether also the Series 80000, similar to its predecessor, Series 31, will be incorporated in a handbook. This was said to be likely.

There was nothing to report from IUPAC, except for a great interest about the proposed redefinition of the mole.

There was also nothing to report from IUPAP, as declared by P. Mohr on behalf of the official delegate, Prof. W.D. Phillips.

Prof. Kovalevsky reported the result of discussion on the Draft Chapter 2 of the SI Brochure within the "Comité science et métrologie" of the French Académie des sciences. Among the suggestions, there was that of avoiding the qualifier "fundamental" for the constants chosen as the basis for the new SI, and of using instead "reference" or "basic". A further suggestion in this respect was to spend some words in Chapter 2 to explain the meaning of "fundamental" and "invariant". About the second, he proposed a different wording to better specify the connection between the proposed SI definition and the scale unit of the Universal Time (TAI or UTC). He also proposed to introduce a specific symbol, suggesting S, for $\Delta\,(^{133}\mathrm{Cs})_{\mathrm{hfs}}$. This would greatly simplify the text of the whole Chapter. When the definition of the second is changed, only S will have a new expression, and the reading of the definition of other units will remain correct. Otherwise, all the formulae involving this quantity will have to be rewritten. He also remarked that the number of digits with which numerical values are given is not always consistent through the Chapter. He then reported that within the Académie des sciences there are serious concerns about fixing the value of the Avogadro number (sic). He concluded with the purposely paradoxical remark that in the new SI many units, among which the ampere, will be based on counting, which itself could be expressed in moles. Therefore it could be inferred that the ampere is defined in terms of the mole, which might induce to wonder whether it still would deserve the role of base unit.

[Prof Mills has added the following comment when preparing the minutes: At a recent meeting of the Academy Committee at which he was present, the alternative words "fundamental constant", "basic constant of physics", and "constant of nature" were discussed at length. The conclusion at that meeting was that the words "constant of nature" might be preferable to the alternatives.]

Also Prof. Bordé spoke for the Académie des sciences, discussing the strong coupling between the definitions of the time and mass units.

4. REVIEW OF THE STATUS OF EXPERIMENTS RELEVANT TO THE DETERMINATION OF THE VALUES OF THE FUNDAMENTAL CONSTANTS REQUIRED FOR THE REVISED SI

4.1 Watt balances and the measurement of *h*

M. Stock, BIPM, spoke on the status of experiments on the determination of the Planck constant. He reviewed the proposal of revision and its main motivations, i.e., the unknown stability of the International Prototype of the Kilogram, the IPK, and the unsatisfactory situation of electrical metrology, in which conventional representations of the ohm and the volt based on macroscopic quantum effects are preferred to those obtained from the SI unit, the ampere, due to their better reproducibility. Dr Stock explained the redefinition of the kilogram in terms of the Planck constant and its realization by means of the watt balance and of the X-ray Crystal Density, XRCD, experiment. He reviewed the present state and the expected improvements, giving an exhaustive view of the worldwide situation. He compared the situation with the conditions posed by the CCM Recommendation G1 (2013) in terms of accuracy and compatibility of the various experiments; it was clear that in this respect the CCM conditions were not yet met. He then went on to discuss and compare the different impact of the SI revision on mass and electrical metrology, respectively. In the former field, the value of the current reference, the IPK, would remain unchanged. However the uncertainty in mass of the IPK, which is zero in the current SI, would no longer be zero in the new SI: it would take the uncertainty previously attached to the Planck constant. In electrical metrology, on the contrary, the uncertainties in the values of the Josephson and von Klitzing constants, K_J and R_K, would become equal to zero, whereas their values might change significantly with respect to $K_{J\text{-}90}$ and $R_{K\text{-}90}$ (parts in 10^8 for K_J). This fact would not represent a problem, but users should be educated about it.

Prof. Mills asked whether the universality and the exactitude of the relations connecting K_J and R_K to h and e is still under discussion, and the reply was that, according to recent investigations, if corrections exist, they are negligible. R. Davis commented that the agreement between XRCD and watt balance would be an implicit evidence of the exactitude of the formulas.

D. Newell, NIST and CODATA, commented on the fact that, independent of the issue raised by Prof. Mills, the discontinuity mentioned by M. Stock would be noticed anyway. B. Taylor recalled that the adoption of conventional units in 1990 implied a much larger discontinuity (8 in 10^6) which did not create harm, whereas the present situation is better.

B. Wood, NRC and CODATA, supported the optimism by saying that decades of investigations did not show any evidence against the correctness and universality of the equations relating K_J and R_K to the Planck constant h and the electron charge e.

4.2 X-ray crystal density project to determine N_A

H. Bettin, PTB, spoke about the Avogadro constant N_A, its relevance to the revision of the SI and its measurement, with special emphasis on the XRCD experiment. He wondered how many independent XRCD experiments should be considered: actually, the investigation that started as a joint effort among many institutions, each determining one or more of the input quantities, has progressively evolved to the present situation, in which all the input quantities but one, the Si lattice parameter, are measured by more than one participant. The lattice parameter will be determined by a second laboratory, the PTB, within 2015. H. Bettin then reviewed the various contributions to the relative uncertainty of N_A, currently equal to 2.5×10^{-8}, and their anticipated decrease until 2017, the final target being 1×10^{-8}. He then discussed the merits of the present definition of the mass unit, allowing a consistency of 1×10^{-8} at the level of the kilogram, and its disadvantages, mainly ascribed to the unknown stability of the IPK, but also to the long interval between two verifications. He also highlighted the situation of the molar Planck constant N_Ah, whose CODATA recommended value changed between the 2006 and 2010 adjustments by an amount one order of magnitude larger than the associated uncertainty. Based on this uncomfortable situation, he warmly wished a new determination, based on different principles. He then went to the proposed new definition of the kilogram, comparing its merits and disadvantages. Among the merits, he mentioned ease of realization (one week using a silicon crystal characterized by means of the XRCD experiment), long-term stability and improvability. As to disadvantages, the new definition is difficult to understand, both in principle, as the connection to h is obscure to non-physicists, and because of some complication in the wording, on which he suggested a simplification. He also said that the proposed definition is claimed to define h but actually defines K_J and R_K. In addition, the atomic-weight scale would be excluded by the redefinition. Finally, the present situation concerning the uncertainty on h is such that the revision of the SI, at least for the first years, will sacrifice mass metrology for electrical metrology.

H. Bettin then went to the proposed new definition for the mole, and asserted that the Avogadro project also realizes the new definition of the mole, as was previously said. He seemed to regret that in the new definition the connection with mass is broken, as the mole is often realized by weighing a mass.

In the subsequent discussion B. Wood, commenting again on the functions relating K_J and R_K to h and e, asserted that, should it be demonstrated in a future that they are different from what we currently believe, this would not impact on the SI, as the numerical values of h and e would be unaffected.

W. Bich noted that the same method, the XRCD experiment, will appear in both *mises en pratique* of the kilogram and the mole. This seems to go in the direction opposite to that of the new SI, in which the two units will be separated. B. Taylor objected that the link between mass and amount of substance will not be broken: it will only become (slightly) uncertain. W. Bich replied that this uncertainty, as small as it might be, marks a deep conceptual difference.

S. Karshenboim insisted that it should not be difficult to understand the new definition of the mole. W. Bich replied that this is true but, as people already tend to make confusion between amount of substance and mass, using the same experiment to realize the definitions of the corresponding units will probably contribute to increase confusion. In this respect, Prof. Mills pointed out that mass and amount of substance are two different ways to quantify different properties of matter. Furthermore, the new definition of the mole nicely clarifies the relationship between counting and amount of substance.

B. Wood objected to the statement that atomic weights would not be affected by the redefinition. Actually, by fixing *h*, the atomic weights would be obtained with very small uncertainties.

C. Williams said that the SI revision should not be seen solely in terms of the advantages of a unit at the expenses of another unit, but as a profound change of the whole system which ultimately will be advantageous to its global consistency.

4.3 Determinations of the Boltzmann constant *k*

J. Fischer, PTB and CCT Task group on the SI, started with an overview of the task group, its membership and terms of reference. He then reviewed the six determinations of the Boltzmann constant *k* that contributed to the 2010 CODATA recommended value, of which only two were available at the time of the 2006 adjustment. All of them are based on the same method, the so-called acoustic gas thermometer, AGT, whose present limits are the determinations of the cavity volume and of the relative isotopic abundances of argon (helium being the alternative). He then gave an update to 2013, when the NPL published a new value with the best relative uncertainty so far (0.71×10^{-6}), but discrepant with respect to the second most accurate value, the LNE 2011, having a relative uncertainty equal to 1.2×10^{-6}. The relative difference between the two values is equal to 2.8×10^{-6}, with an uncertainty equal to 1.4×10^{-6}. This is the first discrepancy in the otherwise very good situation of the Boltzmann constant.

J. Fischer then informed about further initiatives, including a joint effort between NIM and NIST based on the AGT method applied to cylindrical resonators. The PTB is developing dielectric-constant gas thermometry, DCGT, an experimental principle based on the relation of the Boltzmann constant with the relative dielectric constant of a gas, high-purity helium in the specific case. The method is technologically challenging in terms of pressure, capacitance and temperature measurements. Resonant ultrasound spectroscopy, RUS, is used to determine the effective compressibility of the capacitor and other parts. Relative uncertainty is 4.3×10^{-6}, the challenge being to reach 2×10^{-6}. The Université Paris 13, together with the LNE, is following since 2004 a laser-spectroscopy method, based on Doppler broadening of NH_3 absorption lines. Present uncertainty is 50×10^{-6}, but further improvements are expected by using a multi-path cell. Another technique, Johnson noise thermometry, has been investigated by NIST jointly with MSL and, more recently, by NMIJ, NIM and INRIM.

J. Fischer presented a summary of the various methods and state-of-the-art uncertainty for each of them, re-stating that the Boltzmann constant is in a good situation as concerns consistency among the various determinations, with only a small recent disagreement which, however, might imply a broadening of the uncertainty associated with the CODATA recommended value, should the discrepancy not be resolved. He then discussed the Recommendation CCT T2 (2010) and the two conditions to be met before the kelvin can be redefined in terms of the Boltzmann constant. These are that "…a relative standard uncertainty of the value of *k* of order one part in 10^6 be obtained, based on measurements applying different methods of primary thermometry", and that "…these measurements ideally include at least two fundamentally different methods…". He noted that the former condition is currently met and commented that the CODATA TGFC might recommend in 2014 a new value for *k* with a relative uncertainty of 5×10^{-7}. After redefinition the relative uncertainty of the triple point of water would be the same, corresponding to an absolute uncertainty of about 0.14 mK. He also presented a correlation matrix between different estimates obtained by the same laboratory at different times and by different laboratories. He concluded with the PTB

comments on the strategy documents prepared by the Consultative Committees and on the role of the BIPM. These comments are reflected in a formal PTB proposal that is accounted for under item 5 below.

In the subsequent discussion, C. Williams pointed out that the results from different methods looks consistent, so that both requirements seem to be already fulfilled. Prof. Mills asked whether samples of enriched argon might be used, similarly to what is done in XRCD for silicon, the reply being that the cost would be too high. Upon a request by C. Thomas, Executive Secretary of the CCU, D. Newell explained that in the CODATA adjustment those data contributing less than 1 % to a recommended value are disregarded (the so-called 1 % cut-off rule). This, explained B. Wood, is a direct consequence of expressing uncertainties with two digits. D. Newell added that the 1 ppm relative uncertainty on the Boltzmann constant might be met as well, even considering the current discrepancy of the most recent determinations.

4.4 CODATA TGFC report on the analysis of the currently available data from these experiments

D. Newell, chair of the CODATA Task group on fundamental constants, TGFC, talked about their activity. He gave first a brief historical account about the establishment of the CODATA, in 1966, and of the task group, in 1969. The task group is reviewed every two years by CODATA, the last review having been very positive. D. Newell mentioned the important role assigned to the task group by the 24th meeting of the CGPM with its Resolution 1 and announced that the closing date for the next scheduled adjustment is Dec. 31, 2014. He then showed data from a 2013 incomplete, unofficial adjustment especially focused on the four constants relevant to the new SI, i.e., h, e, k and N_A, on the fine structure constant α, the Rydberg constant R_∞, and the gravitational constant G. These 2013 unofficial adjusted values now include data previously not considered, among which two new determinations of α, yielding small changes of the adjusted value of this constant and its uncertainty, a new, discrepant determination of the proton charge radius, which impacts on the value of the Rydberg constant, and a further BIPM determination of G consistent with the first (2001) within its (slightly smaller) uncertainty.

5. CCU RECOMMENDATION TO THE CIPM ON THE FUTURE REVISION OF THE INTERNATIONAL SYSTEM OF UNITS

5.1 Discussion of the text of a Recommendation to the CIPM

C. Thomas presented the text of a CCU Recommendation to the CIPM, drafted in advance to allow review by the CCU delegates, together with an integration proposed by the PTB. The recommendation is a generic encouragement to all the involved parties to continue efforts in order to enable the 26th meeting of the CGPM to promulgate the new SI. The PTB integration aimed at giving the relevant Consultative Committees a special power in peer reviewing and scrutinizing the data to contribute to the CODATA least-squares adjustment, beyond the usual peer-review activity carried out for publications.

In the subsequent discussion, many criticisms were raised against the PTB proposal. Some, among which T. Quinn, feared that the proposal would imply an (undesirable) increase in bureaucracy. He also expressed his persuasion that only those who did the experiments can meet and discuss their results. J. Stenger, on behalf of the PTB, replied that the involved experiments are going to become realizations of SI units, therefore it is natural that the Consultative Committees take over responsibility for the quality of the data. In addition, most countries are represented in the Committees. Ph. Richard put forward the example of the CCM, which choose to validate the relevant data through a key comparison. J. Fischer claimed that acceptance of the PTB proposal might help scientists to persuade their managements to go on funding experiments. T. Quinn insisted that the scrutiny of the realizations of the units should be kept separate (as it is now) from analysis of data for the least-squares adjustment, and that the existing procedures, as implemented by the CIPM MRA and the CODATA TGFC, respectively, are perfectly apt to manage the process towards the new SI. P. Mohr, supported by C. Williams, expressed the view that the latter task, i.e., that of analysing input data to the adjustment, is to the CODATA TGFC. B. Taylor pointed out that the Committees are already playing the roles the PTB proposal would assign to them, and that the proposal does not modify significantly the substance of the original text of the recommendation. While supporting this, Prof. Himbert noted that, as written, the proposal might even sound offensive towards both the CIPM and the CODATA TGFC and should therefore (in the least) be reformulated, at which J. Stenger replied that it was not the intention of the PTB to be offensive, but constructive. S. Karshenboim elaborated on an example presented by T. Quinn, wondering which Committee might decide on the discrepancy between XRCD and watt balance experiments. M. Milton expressed his perplexity on the practical implementation of the proposal, and the feeling that the articulation of the proposal is not clear enough. T. Quinn proposed that it should be up to the CIPM to decide on how to proceed, and J. Stenger declared that this was precisely the rationale of the proposal. T. Quinn and B. Taylor emphasized the crucial role of the CCU in collecting the views of the Consultative Committees and in reporting on them to the CIPM. A. Thompson, NIST, recalled that in Resolution 1 of the 24th meeting of the CGPM the respective roles of the CCU and of the CODATA are clearly identified. B. Wood re-stated his feeling that there is no need to reinforce what is already happening.

Eventually, a small team (M. Milton, T. Quinn, C. Williams and J. Stenger) was established, with the task of revising the recommendation along the lines of the discussion.[1]

5.2 Discussion of the number of digits to be chosen for the values of *h*, *e*, *k*, and N_A

B. Taylor presented a document by himself and D. Newell on choosing the appropriate number of digits for the exact values of the constants involved in the SI revision. The values of some constants, e.g., the mass of the IPK, are exact in the current SI but will acquire an uncertainty in the new SI, and will possibly change over time according to their experimental determinations. He showed that, of the eight constants in the situation described above, only four are independent, namely: the mass of the IPK, $m(\mathcal{K})$, the magnetic constant, μ_0, the molar mass of the ^{12}C atom, $M(^{12}\mathrm{C})$, and the temperature of the triple point of water, T_{TPW}. To avoid any discontinuity in the magnitudes of the units that will be redefined, it is necessary that the initial values (in new SI units) of the above mentioned constants be equal, within their uncertainty, to the exact values in "old" SI units. The goodness of this agreement depends on the number of digits chosen for the exact values of the constants involved in the SI revision. B. Taylor proposed and discussed four options with increasing number of digits. The

[1] This team fulfilled its task during the meeting – see item 5.2, last paragraph.

four cases fulfil the equality condition to different degrees, only the fourth, the one with the largest number of digits, ensuring equality to the least significant digit. Various opinions were expressed in the subsequent discussion. R. Davis was in favour of case 1, whereas J. Fischer declared that the CCT would be in favour of the intermediate cases 2 or 3, Prof. Mills joining him in this preference. The aesthetic issue of giving the values of the constants with the same number of digits (case 3) was also raised, but the attendance did not consider this to be important. P. Mohr clarified that it is premature to take a decision prior to the last adjustment before the redefinitions, and that the intention in presenting the document was simply to draw the attention of the CCU to the problem. B. Taylor wondered whether equality to the least significant digit should be sought, which would imply choosing case 4, and B. Wood replied that the initial values would change anyway with time, so that strict equality is not necessary. For similar reasons, M. Stock favoured case 3. W. Bich recalled that the IUPAC Commission on Isotopic Abundances and Atomic Weights, CIAAW, gives, beside an unabridged table of standard atomic weights, tables abridged to four and five significant digits. S. Lea expressed his unhappiness in giving digits beyond the standard uncertainty. W. Bich favoured a strict equality at the time of the redefinition.

Eventually, following a suggestion by T. Quinn, a small working group, made by B. Taylor, D. Newell, W. Bich and J. Fischer was established with the task to produce a document giving advice on the issue. Later on, after consultation among the members of the working group, B. Taylor went back to the issue of the number of digits, and noted that Recommendation 1 of the 24th meeting of the CGPM leaves no room to interpretations other than the numerical values of the four constants expressed in the "old" and "new" SI units should be strictly equal at the time of the redefinitions. As a consequence, case 4 will probably be chosen. The task of the working group was thus considered fulfilled.

To conclude Item 5.1 of the Agenda, J. Stenger showed the text of the CCU Recommendation to the CIPM, after modification from the small group mentioned under Item 5.1, and discussed its changes with respect to the original proposal and the PTB proposal. It was universally acknowledged that the role of Consultative Committees and NMIs in validating the input data to CODATA adjustment is now clearer. Therefore, the recommendation was approved by the CCU in its English version. As usual, the BIPM will produce a French translation in the coming weeks, with possibly minor editorial changes also to the English version.

6. REVIEW OF THE DRAFT REVISION OF CHAPTER 2 OF THE SI BROCHURE

T. Quinn presented his document on the order in which the symbols of units should be written in composed symbols. To introduce the problem, he made an historical *excursus* starting from Resolution 12 of the 11th meeting of the CGPM (1960), in which the newton is written in terms of the symbols of its base units as kg m s^{-2}. In the first SI Brochure, this order was changed, with no evidence of a formal decision, to m kg s^{-2} and has remained the same until nowadays. T. Quinn's question was, taking as a case example the Planck constant h, whether its unit, J s, should be written in terms of base units as kg m^2 s^{-1} according to the style of Resolution 12 of the 11th meeting of the CGPM, or m^2 kg s^{-1} as in the current SI Brochure, or s^{-1} m^2 kg according to the new order of definition of the base units. He went on discussing the practice in ISO, IUPAP and IUPAC and concluded with the proposal to return back to the style of the CGPM Resolution. That order, he

argued, is the one that best reflects the usual defining equations for the corresponding derived quantities.

On the same subject, B. Taylor presented a revision of Tables 3 and 4 of the SI Brochure. In both Tables T. Quinn's proposal is adopted, but a further column is added in Table 3 with the base units listed in the order in which they are defined in the new SI. This further column is intended for ease of comparison.

There was a short discussion on T. Quinn's proposal, ending in wide agreement. Most, among which Prof. Pendrill and E. Prieto (who sent a message on this), were in favour. W. Bich said that the order in which the base units are defined has no special physical meaning, so that it should not prevail over common sense. S. Karshenboim said that the defining physical equations should be given, at which T. Quinn replied that they can be found, for example, in the ISO/IEC 80000 Series. The discussion ended with wide agreement that Quinn's proposal be adopted.

As to B. Taylor's proposed revision, some debate took place on the opportunity of a further column in Table 3. M. Stock was opposed, for the sake of clarity and simplicity. Prof. Obdržálek was also opposed. Eventually, the President summarized the discussion by saying that the meeting had expressed a preference for the order of units to reflect the underlying physics rather than any rigid rule, and that in agreeing to the proposed change in order of unit symbols the proposal to add the extra column was not accepted.

Prof. Mari, IEC/TC1, presented his personal view on the common format of the definition of base units. He proposed to remove the words "magnitude" and "when it is expressed" as unnecessary. In addition, "magnitude" is undefined. T. Quinn, supported by Prof. Mills and J. Fischer, defended "magnitude", as absolutely necessary in the definition and "when it is expressed" as appropriate. J. Stenger suggested a simpler formulation, in which "numerical value" is avoided, at which Prof. Mills replied that only the numerical value of a quantity, and certainly not its value, can be fixed. R. Davis supported the current formulation, which has the further merit of giving hints on quantity calculus. J. Schwob, ISO/TC12, objected that "magnitude" is very specific of English, the French counterpart (amplitude) being unsatisfactory, as that same term is also the French counterpart of "amplitude". S. Lea proposed "grandeur" but Prof. Himbert explained that this term is the French word for "quantity". A similar situation exists for Italian, as explained by W. Bich. Prof. Mills suggested taking note of the issue and think on it, and so it was decided.

The revision continued with many editorial remarks, including some already made under previous agenda items, such as the issue of the wording "fundamental constants", criticized by many and still to be solved, or that of the definition of the second, about which S. Karshenboim re-stated a proposal aimed at better specifying the transition frequency. Prof. Mari raised an objection to the term "representation" in the expression "secondary representations of the second", but F. Arias explained that this is precisely the accepted term. T. Quinn recalled the origin of the term, first introduced in 1990 in connection with conventional electrical units.

Prof. Mills commented that every effort had been made to write simple and easily understood explanations for the new definitions, but unfortunately it was not possible to find simple words to explain the kilogram in terms of the Planck constant. T. Quinn replied that this is not a fault of the writers, rather a consequence of the fact that quantum mechanics is not simple. It was agreed to establish a small editorial group to revise the draft. The group, made by Prof. Mills, Prof. Himbert, P. Mohr, T. Quinn, J. Stenger and C. Thomas, was invited by Prof. Mills to meet in September at Reading, UK, with the intention to finalize the revision before the October CIPM meeting.

7. POSSIBLE TIMELINE FOR THE ADOPTION OF THE REVISION OF THE INTERNATIONAL SYSTEM OF UNITS

According to the President, no formal timeline can be anticipated, as it depends on progress in experiments. The most the CCU can do is to offer a revised draft of Chapter 2 of the SI Brochure to the CIPM by the time of their meeting in October.

8. REVIEW OF THE STATUS OF THE MISES EN PRATIQUE OF THE NEW DEFINITIONS OF THE KILOGRAM, AMPERE, KELVIN, AND MOLE

The President introduced the topic by expressing his positive feelings about the situation of the *mises en pratique*, especially that concerning the definition of the kilogram. This was presented by H. Bettin in his capacity as chairman of CCM WGR-kg. He first outlined the genesis and development of the document, subsequently outlining its content, divided into realization of the definition and dissemination. He also discussed some specific aspects, such as the detailed plan of comparisons envisaged in the *mise en pratique*, and announced that a special issue of *Metrologia* is planned on this topic. R. Davis and H. Bettin replied to a question from Prof. Mills explaining some aspects of the in-air *vs* in-vacuum weighings.

B. Wood reported about the *mise en pratique* for the definition of the ampere. This has been prepared, and the Draft approved by the CCEM in 2009.

J. Fischer reported about the *mise en pratique* for the definition of the kelvin, whose first draft dates back to 2006. He outlined the contents of the version to be used with the new definition of the kelvin, approved by the CCT in May 2013.

R. Wielgosz reported about the *mise en pratique* for the mole, which has been available since June 2012. At the 19th meeting of the CCQM, in April 2013, a new proposal concerning the realization of the new definition of the mole came from the PTB, based on a silicon sphere. The updated version implementing the proposal is being prepared.

9. DISCUSSION ON THE EXPRESSION OF MEASUREMENT RESULTS FOR DIMENSIONLESS QUANTITIES: COUNTING/ENUMERATION, CYCLICAL QUANTITIES SUCH AS ANGLE, AND THE USE OF PSEUDO-UNITS FOR SOME DIMENSIONLESS QUANTITIES SUCH AS "MOLECULE" (CONCENTRATIONS IN "MOLECULES PER CM^3")

The President contextualized the discussion recalling that, in the current SI, all quantities subjected to counting, such as entities (be they molecules or other), cycles, events and so on are dimensionless, so that they all share the common unit one. A similar situation holds for radian and steradian. He

mentioned four relevant notes from P. Mohr, Prof. Phillips and himself, and invited discussion on what could be done on the subject, as the guidance given in the current SI Brochure seems to be inadequate. He suggested that perhaps an extra short chapter might do the job.

P. Mohr gave a first presentation of a note by himself on angles and their unit, the radian. Angle is currently dimensionless by its definition, so that cycle, radian and steradian are merely special names for one. As a consequence, serious ambiguities and inconsistencies arise, epitomized by the equality $2\pi = 1$, wrong yet formally allowed within the current SI rules. This causes confusion and is a source of potential numerical mistakes, especially in computer software. A way of fixing this drawback is to define angles in such a way that they are dimensional quantities. In this way, it would no longer be allowed to omit the units radian or steradian. He discussed the broader implication of this choice, especially on exponential quantities, and, for example, on the reduced Planck constant $\hbar$.

P. Mohr then presented Prof. Phillips' note, dealing essentially with the same problem, but focused on random phenomena. In these cases, ambiguities add to ambiguities, as not only angular velocities and frequencies, but also decay rates can be and are easily confused, since their SI unit is the same, i.e., s^{-1}. He gave some examples, among which one concerning *cooperativity*, a quantity relevant to quantum electrodynamics made of a ratio of periodic and stochastic quantities. In some instances, the above described ambiguities did involve errors of 2π or $(2\pi)^2$.

Both authors in their notes expressed the view that the CCU should take the task of giving clear guidance in order to minimize the risk of mistakes and confusion.

R. Wielgosz presented the Recommendation CCQM Q1 (2011). It concerns counting, or enumeration, not to be confounded with amount of substance, and substantially asks the CCU to extend the SI Brochure to provide guidance on units for the expression of measurement results based on counting (enumeration). He explained that this topic is important in diagnostics and in health care in general, as well as in legal matters. He also mentioned a note by H. Parkes, LGC, aimed at raising the attention of the CCU to the need of guidance on enumeration also in the field of bio-measurements.

The President said that, once the problem described, the Committee should look for solutions. According to J. Stenger, in the SI Brochure clear rules are established, and it is not the affair of the CCU to prevent people from making confusion. P. Mohr replied that inconsistencies exist and should be fixed. In W. Bich's opinion, there are (at least) two distinct, although related, issues, one concerning angles and their unit and another concerning counts of events or entities. Problems arise in the former issue from the fact that angles are dimensionless quantities, in the latter because in the current SI there is no way to label what is actually counted. The two issues share the feature that quantities that matter are dimensionless in the SI. B. Taylor agreed.

Prof. Mills objected to give a dimension to new quantities, and would simply be tolerant on "pseudo quantities" such as molecules, counts, entities, etc.

C. Williams went back on the inconsistency concerning angles and on the difficulty to instruct a machine to correctly interpret the different situations. S. Karshenboim made a parallel between the terms "entity" and "ppm" which is not a unit, yet it is accepted and widely used. In addition, he said that the task of the CCU is to define a system of units rather than to solve related practical problems, at which R. Wielgosz replied that, as there is a clear request from the chemical community, the issue should be addressed.

C. Williams suggested a small committee to be set up with the task to propose a recommendation to the CCU. Prof. Obdržálek recommended that when using "units of counting" *ad hoc* names should be used for the unit. This would allow to compare, for example, 10 euros, 20 pounds and 30 dollars, or 1 mole of hydrogen atoms (H) and 1 mole of hydrogen molecules (H_2). W. Bich pointed out that this

already happens with the mole. In addition, coming back to the issue of angles, he said that the fact that angle is dimensionless has important consequences to photometry. In this respect, P. Blattner reminded that, in photometry, attention is devoted to the subject, as shown by a special note in the SI Brochure. M. Milton suggested that the tasks of the small committee suggested by C. Williams should be better specified. Prof. Mills expressed the view that sometimes it is good to include units, some other times it is better not to include them. On a question by C. Thomas about the CCQM Recommendation on enumeration, R. Wielgosz replied that not only confusion at the academic level, but also ambiguity at the regulatory level can arise. The President commented that it is neither necessary nor appropriate to write a textbook, supported in this by R. Wielgosz. Prof. Himbert recalled that basically the quantity should first be defined, which leads to the appropriate unit to use. He also suggested that chapter 2 or 5 of the SI Brochure might be the right places where some material might be added for cases when confusion arises. In alternative, a short Annex could be prepared. J. Stenger objected that the SI Brochure might not be the right place at all. W. Bich commented that it is good to give guidance in the SI Brochure, but the documents presented, especially about angles, show that there is a problem within the SI, so that perhaps some modifications should be considered to the SI itself. Prof. Férard insisted that the unit in a quantity value cannot indicate which the quantity is. This is particularly clear with the examples of SI unit one. In the new version of the Silver Book, ten different examples using the unit "one" for the expression of their values are listed: number fraction, volume ratio, relative mass, substance fraction, solid angle etc. That is the reason why the NPU committee (IUPAC-IFCC) has developed a structured format in which a "kind-of-quantity" and a unit should always be mentioned.

T. Quinn recalled that there has always been reticence to create special names for units, but the time might have come for the unit "one".

It was eventually decided that a small group be formed, made by Prof. Mills, P. Mohr and R. Wielgosz, with the task to suggest the terms of reference for a larger group to be established in due course. Everyone was invited to contribute to help progress on what the President declared to be a formidable problem.

10. THE DEFINITION OF THE YEAR

S. Lea, NPL/SUNAMCO, introduced the topic of the definition of the unit "year". He commented a document authored by himself, in which he gives an outline of the present, ambiguous situation and expresses his personal views to rationalize it. Contrary to the minute, hour and day, all defined as multiples of the second, the year is not defined in the SI. Yet, it is used in physics, chemistry, geology and other earth sciences whenever the use of the second is unpractical. Unfortunately, there are several competing definitions of the year, notably the mean Julian, the mean Gregorian (IUPAC), and the tropical, or solar year, the last of these being defined, in turn, as referred to the year 1900 (thus related to Recommendation 9 of the 11th meeting of the CGPM, 1960) or 2000 (according to a IUPAC-IUGS Recommendation). Their durations differ by about 2×10^{-5}. A further source of confusion is given by different names, year and annus, and symbols, yr, a, used. Even multiples are designated in different ways, also depending upon a distinction between duration and age which is commonly adopted in geosciences. S. Lea also mentioned some further ambiguity related to the reference frame defining the time scale adopted, be it Terrestrial Time, TT, or other. He ended his

overview by offering his personal views on the definition (mean Julian, an exact multiple of the second), name (year) and symbol, (a, with subscripts when appropriate). In addition, the unit second should be preferred when expressing primary reference data.

Subsequently, F. Arias, Director of the BIPM Time Department and Executive Secretary of the CCTF, reported on the recommendation formulated by the CCU *ad-hoc* group on the definition of the year, chaired by N. Capitaine and created at the 19th meeting of the CCU. She explained that the tropical year "which governs the seasons and is the basis of the calendar" is however badly defined, as it decreases over time. For this and other reasons, the proposal of the *ad-hoc* group is to adopt a specific tropical year, i.e., the tropical year 1900, preferred to the tropical year 2000, recommended by the IUPAC-IUGS. N. Capitaine gave further reasons, discussing the Julian year, widely used in astronomy as it is used in series development (e.g., polynomials) of quantities that are function of time. Prof. Obdržálek stressed the need to distinguish between time interval and time duration. Further, he drew attention to the question of the zero point in dating systems, i.e. the beginning of year 1, noting that in some calendars the year with number zero is not used. In the International Electrotechnical Vocabulary (IEV) and ISO/IEC 80000-3 "Quantities and Units, Part 3, Space and Time" a distinction is made among time instant, time interval and time duration. He insisted that it is necessary to mention both the duration of a (given) year and the starting point (i.e., the beginning of the year 1), similarly to what happens in thermometry. F. Arias replied that two separate issues should be considered. First, the initial and final events are dated on the time scale, then the duration of the time interval is expressed in the chosen unit, e.g., the tropical year 1900. She explained that the *ad-hoc* group tried to remain in the framework of the SI Brochure, in which the tropical year 1900 is already mentioned, being the base for the 1960 definition of the second. An objection to this came from S. Lea, i.e., the day would be different from the day as defined in TAI or UTC. S. Karshenboim did not see special advantages in any of the possible alternative definitions of the year. K. Fujii, NMIJ/AIST, reported that in Japan the need for an unambiguous definition is strongly felt. W. Bich was in favour of the *ad-hoc* group proposal, considering the historical link of the tropical year 1900 to the SI second, whereas Prof. Pendrill favoured the mean Julian year for its simplicity.

Prof. Himbert wondered about the role of, and the expectation from the CCU regarding this issue. Is the Committee expected to include some guidance in the Brochure, or to prepare a recommendation to the CIPM? In this respect, R. Wielgosz recalled the origin of the involvement of the CCU, namely, a request by the IUPAC to give advice. This task was fulfilled, according to F. Arias, through a written reply and a joint meeting, with no further reaction from IUPAC. It appeared that the CCU is not in a position to settle the issue once and for all because the definition to choose depends upon the application. For instance, the adoption of the tropical year of 1900 is favoured for expressing very long intervals, for applications in chemistry and geological sciences. Eventually, upon a suggestion by C. Thomas, it was decided to contact IUPAC through I. Villa, one of the authors of the IUPAC-IUGS recommendation, reporting the formal discussion within the CCU and sending to him the *ad-hoc* group recommendation for comments. In addition, according to the general feeling, it was also decided that, since it would be difficult to insert the year among the units in the SI Brochure, because of various existing definitions, the CCU for the moment should not take any further action.

Prof. Himbert suggested that, should in a future the CCU decide to insert the year in the SI Brochure, the appropriate place would be Table 8.

Prof. Mills expressed his thanks to the *ad-hoc* group on the definition of the year, which really did its best to sort out this question. There is no other pressing task for this group at the time being, but experts may still be consulted in future.

11. UNITS FOR ASTRONOMY

N. Capitaine reported on the IAU 2012 Resolution B2 on the redefinition of the astronomical unit of length as an exact multiple of the metre, with a new symbol: au. She discussed the advantages of the new definition, the most relevant being that deviation from the SI is now eliminated, and the impact on the SI Brochure, i.e., a move of the unit from Table 7 to Table 6. The difference with respect to the previous definition would be less than 1×10^{-10}. S. Karshenboim elaborated on the novel dependence of the astronomical unit from the metre, remarking that the new definition implies that the au is now determined in terms of caesium frequency and speed of light.

The CCU took note of the necessary modifications to the SI Brochure.

12. RECENT MODIFICATIONS BROUGHT TO THE CURRENT APPENDIX 2 OF THE SI BROCHURE

C. Thomas explained that it is now a recurrent action for the CCU Executive Secretary to contact the other CC Executive Secretaries six month ahead of a CCU meeting, requiring them to check the status of the Appendix 2 of the SI Brochure. She recalled that it concerns the current *mises en pratique* of the seven base units, which are kept under electronic form only on the open BIPM web site for easy modification when needed.

The *mise en pratique* for the kelvin was updated by the CCT in October 2011, and a change of editorial nature was brought to the *mise en pratique* of the mole in October 2012.

The most recent updates (June 2013) apply to the second and the metre.

The update on time mainly concerns information and statistical data relevant to the international time scales, UTC and TAI, which are constantly in evolution. The table giving values recommended jointly by the CCTF and the CCL for applications including the practical realization of the metre (MeP) and secondary representations of the second (SRS) was updated. The updates concerned fifteen frequencies, two of them being new entries. At the time of the CCU meeting, the CIPM had approved frequencies and uncertainties but not yet adopted the ultimate version. C. Thomas concluded by expressing her thanks to the CC Executive Secretaries who help keeping Appendix 2 up-to-date, and also to J. Miles for her dedicated work in programming the corresponding BIPM web page.

13. FUTURE MODIFICATIONS OF THE SI BROCHURE OTHER THAN IN CHAPTER 2

13.1 Modifications decided at previous meetings of the CCU

C. Thomas explained that the decisions taken in the past are not yet into force because there is not yet a new SI Brochure. However, she keeps note of any change in a regularly updated file. Various suggestions were mentioned and noted, from N. Capitaine, Prof. Kovalevsky and W. Bich.

13.2 Review of Tables 6 to 9 of the current SI Brochure

B. Taylor noted that, if the SI Brochure will not be updated until the presumable time of the promulgation of the new SI, the interval between the current and the next editions would be about twenty years, considerably longer than usual. He suggested publishing an electronic version in which the changes so far decided could be included. M. Milton objected that, although changes are comparatively minor, the web-based version would be different from the printed one. This inconvenience could be remedied by inserting an explanatory page in the printed version and some lines in the web version. P. Mohr wondered whether the CIPM should in any case approve the changes. T. Quinn pointed out that, since the SI Brochure is a formal document, if the conditions are such that an update is envisaged of the web-based version, also the printed version should be updated, which incidentally would involve a minor extra effort. C. Williams commented that young people no longer look at paper and the electronic version alone could be maintained on the BIPM website. T. Quinn objected, supported in this by J. Stenger and W. Bich, that this solution would raise the problem of which would be the official document between the two different versions. Prof. Pendrill profited of the discussion to inform that ISO would like to put forward some comments on Section 1.2. As to the amount of changes, T. Quinn suggested that some material from draft Chapter 2 of the future Brochure could be useful even before the redefinitions, so that it might be worth waiting for the outcome of the September meeting of the dedicated working group. M. Milton suggested to put this issue of a new edition of the SI Brochure on the agenda of the next CCU, at which T. Quinn replied that most of the changes agreed during the meeting refer to tables only, so the task might be less heavy than expected and could be undertaken before the next CCU meeting. Also B. Taylor favoured this timeline and suggested to fix a date for the publication of the Brochure. He expressed the view that in six months a draft could be circulated, at which M. Milton, supported by Prof. Mills, objected that material on dimensionless quantities might take longer. B. Taylor replied that the issue concerning the radian might be fixed earlier, so that a new Brochure might be available by 2015.

No consensus having been reached, no firm decision was taken.

14. ANY OTHER BUSINESS

The President announced that, after 17 years leading the CCU and its meetings, the time had come to resign from his position. Among many others, he thanked especially T. Quinn, a wise counsellor, B. Taylor and P. Mohr, and C. Thomas. T. Quinn, interpreting the general feelings, warmly thanked him for the service he gave to metrology, and highly praised his towering personality. B. Inglis, CIPM, who in the meantime had joined the meeting, spoke in his capacity as president of the CIPM and also warmly thanked Prof. Mills. The attendance joined giving the CCU President a standing ovation.

15. DATE OF NEXT CCU MEETING

No specific date was decided. The next meeting would take place indicatively in two years.

The President closed the meeting by wishing all participants a nice trip back.

September 2013

Walter Bich

Ian Mills

Claudine Thomas

FOLLOW-UP OF THE 21ST CCU MEETING

Two working groups were established

- **On the Draft revision of Chapter 2 of the SI Brochure (item 6 of the agenda)**:

  Prof. Mills, Prof. Himbert, P. Mohr, T. Quinn, J. Stenger and C. Thomas. The team was invited by Prof. Mills to meet in September at Reading, UK, with the intention to finalize the revision before the October CIPM meeting.

- **On the expression of measurement results for dimensionless quantities (item 9 of the agenda)**:

  Prof. Mills, P. Mohr and R. Wielgosz, with the task to suggest the terms of reference for a larger group to be established in due course.

Annex: CCU Recommendation to the CIPM U 1 (2013)

Proposal to the CIPM on elements for a draft resolution on the revision of the International System of Units, the SI, for the CGPM at its 25th meeting

- **Revision of the International System of Units, the SI**

Draft Resolution A

The General Conference on Weights and Measures (CGPM), at its 25th meeting,

recalling

- Resolution 1 adopted by the CGPM at its 24th meeting (2011), which takes note of the intention of the International Committee for Weights and Measures (CIPM) to propose a revision of the SI that links the definitions of the kilogram, ampere, kelvin, and mole to exact numerical values of the Planck constant h, elementary charge e, Boltzmann constant k, and Avogadro constant N_A, respectively, and which revises the way the SI is defined including the wording of the definitions of the SI units for time, length, mass, electric current, thermodynamic temperature, amount of substance, and luminous intensity so that the reference constants on which the SI is based are clearly apparent,
- the many benefits summarized in Resolution 1 that will accrue to science, technology, industry, and commerce from such a revision, especially from linking the kilogram to an invariant of nature rather than to the mass of a material artefact, thereby ensuring its long-term stability,
- Resolution 7 adopted by the CGPM at its 21st meeting (1999), which encourages work at the National Metrology Institutes (NMIs) that can lead to such a redefinition of the kilogram,
- Resolution 12 adopted by the CGPM at its 23rd meeting (2007), which outlines the work that should be carried out by the NMIs, the International Bureau of Weights and Measures (BIPM), and the CIPM together with its Consultative Committees (CCs) that could enable the planned revision of the SI to be adopted by the CGPM,

considering that there has been significant progress in completing the necessary work, including

- the acquisition of relevant data and their analysis by the Committee on Data for Science and Technology (CODATA) to obtain the required values of h, e, k, and N_A,
- establishment by the BIPM of an ensemble of reference standards of mass to facilitate the dissemination of the unit of mass in the revised SI,
- the preparation of *mises-en-pratique* for the new definitions of the kilogram, ampere, kelvin, and mole,
- awareness campaigns to alert user communities as well as the general public to the proposed revision of the SI,

- the preparation of a new edition of the SI Brochure that presents the revised SI in a way that can be readily understood by a diverse readership,

that despite this progress the data do not yet appear to be sufficiently robust for the CGPM to adopt the revised SI at its 25th meeting,

encourages

- continued effort in the NMIs, the BIPM, and academic institutions to obtain data relevant to the determination of h, e, k, and N_A with the requisite uncertainties,
- the NMIs to continue acting through the CCs to discuss and review this data,
- the CIPM to develop a plan to provide the path via the CCs and the CCU for implementing Resolution 1 adopted by the CGPM at its 24th meeting (2011), and
- continued effort by the CIPM, together with its Consultative Committees, the NMIs, the BIPM, and other organizations such as the International Organization of Legal Metrology (OIML), to complete all work necessary for the CGPM at its 26th meeting to adopt a resolution that would replace the current SI with the revised SI, provided the amount of data, their uncertainties, and level of consistency were deemed satisfactory.

Annexe : Recommandation du Comité consultatif des unités (CCU) présentée au Comité international des poids et mesures (CIPM) U 1 (2013)

Propositions faites au CIPM relatives à un projet de résolution sur la révision du Système international d'unités (SI) à soumettre à la CGPM lors de sa 25e réunion

- **Sur la révision du Système international d'unités, le SI**

Projet de résolution A

La Conférence générale des poids et mesures (CGPM), à sa 25e réunion,

rappelant

- la Résolution 1 adoptée par la CGPM à sa 24e réunion (2011) qui prend acte de l'intention du Comité international des poids et mesures (CIPM) de proposer une révision du SI consistant à relier les définitions du kilogramme, de l'ampère, du kelvin et de la mole à des valeurs numériques exactes de la constante de Planck h, de la charge élémentaire e, de la constante de Boltzmann k, et de la constante d'Avogadro N_A, respectivement, et à modifier la façon de définir le SI, ainsi que la formulation des définitions des unités du SI pour les grandeurs temps, longueur, masse, courant électrique, température thermodynamique, quantité de matière et intensité lumineuse, de manière à ce que les constantes de référence sur lesquelles se fonde le SI apparaissent clairement,
- les nombreux avantages, mentionnés dans la Résolution 1, que présentera cette révision du SI pour la science, la technologie, l'industrie et le commerce, tel que le fait de relier le kilogramme à une constante de la nature et non plus à la masse d'un objet matériel (artefact), ce qui assurera sa stabilité à long terme,
- la Résolution 7 adoptée par la CGPM à sa 21e réunion (1999) qui encourage les laboratoires nationaux de métrologie à poursuivre les expériences visant à parvenir à une telle redéfinition du kilogramme,
- la Résolution 12 adoptée par la CGPM à sa 23e réunion (2007) qui décrit les travaux devant être effectués par les laboratoires nationaux de métrologie, le Bureau international des poids et meures (BIPM), ainsi que le CIPM et ses Comités consultatifs, afin de permettre l'adoption par la CGPM de la révision du SI,

considérant les progrès significatifs réalisés afin d'effectuer les travaux nécessaires, parmi lesquels

- l'acquisition des données pertinentes, et leur analyse par le Committee on Data for Science and Technology (CODATA), afin d'obtenir les valeurs requises pour les constantes fondamentales de h, e, k et N_A,
- la mise au point par le BIPM d'un ensemble d'étalons de masse de référence qui permettra de faciliter la dissémination de l'unité de masse une fois le SI révisé,

- la préparation des mises en pratique des nouvelles définitions du kilogramme, de l'ampère, du kelvin et de la mole,
- la mise en place de campagnes de sensibilisation pour informer les communautés d'utilisateurs et le grand public du projet de révision du SI,
- la préparation d'une nouvelle édition de la *Brochure sur le SI* dans laquelle le SI révisé serait présenté de façon aisément compréhensible par l'ensemble des lecteurs,

considérant que, malgré les progrès effectués, les données disponibles ne semblent pas encore suffisamment robustes pour que la CGPM adopte le SI révisé lors de sa 25e réunion,

encourage

- les laboratoires nationaux de métrologie, le BIPM et les institutions universitaires à poursuivre leurs efforts afin de déterminer expérimentalement les valeurs des constantes de h, e, k et N_A au niveau d'incertitude requis,
- les laboratoires nationaux de métrologie à continuer activement à examiner et discuter de ces résultats au sein des Comités consultatifs,
- le CIPM à planifier la mise en œuvre de la Résolution 1 adoptée par la CGPM à sa 24e réunion, en collaboration étroite avec les Comités consultatifs et le CCU,
- le CIPM et ses Comités consultatifs, les laboratoires nationaux de métrologie, le BIPM, ainsi que d'autres organisations telles que l'Organisation internationale de métrologie légale (OIML), à poursuivre leurs efforts afin d'effectuer les travaux nécessaires pour que la CGPM adopte, lors de sa 26e réunion, une résolution permettant de remplacer le SI actuel par le SI révisé, sous réserve que les données obtenues, tant concernant leur nombre, les incertitudes associées ou leur niveau de cohérence, soient jugées satisfaisantes.