Bureau International des Poids et Mesures

Consultative Committee for Units (CCU)

Report of the 18th meeting
(11 – 13 June 2007)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Bureau
international
des poids
et mesures

Organisation
intergouvernementale
de la Convention
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 UNITS AS OF 11 JUNE 2007

President

I.M. Mills, International Union of Pure and Applied Chemistry [IUPAC], Commission STU, Emeritus Professor of Chemistry, Department of Chemistry, Reading.

Executive Secretary

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

Members

Centro Español de Metrología [CEM], Madrid.

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

International Astronomical Union [IAU].

International Commission on Illumination [CIE].

International Commission on Radiation Units and Measurements [ICRU].

International Electrotechnical Commission [IEC], Technical Committee 25.

International Federation of Clinical Chemistry and Laboratory Medicine [IFCC].

International Organization for Standardization [ISO], Technical Committee 12.

International Organization of Legal Metrology [OIML].

International Union of Pure and Applied Chemistry [IUPAC], Commission STU.

International Union of Pure and Applied Physics [IUPAP], Commission SUN AMCO.

National Institute of Metrology [NIM], Beijing.

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

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology [NMIJ/AIST], Tsukuba.

National Physical Laboratory [NPL], Teddington.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

State Committee of the Russian Federation for Standardization and Metrology, Rostekhregulirovaniye of Russia [VNIIM], Moscow.

M. Himbert.

T.J. Quinn.

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

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

The Consultative Committee for Units (CCU)* held its 18th meeting at the International Bureau of Weights and Measures (BIPM), at Sèvres, from 11 to 13 June 2007.

The following were present: J. Bastie (LNE-INM, CIE), C.A. Borghi (IEC/TC 25), N. Capitaine (Observatoire de Paris, IAU), R. Dybkaer (IFCC), J. Flowers (NPL), K. Fujii (NMIJ/AIST), P. Gérôme (ISO), M. Himbert (LNE-INM), Dr S. Karshenboim (VNIIM), A. Leitner (BEV, OIML), Zuliang Lu (NIM), I.M. Mills FRS (President of the CCU, IUPAC), P. Mohr (NIST, IUPAP), D.B. Newell (NIST, CODATA), E. Prieto (CEM), T.J. Quinn CBE FRS (Director Emeritus of the BIPM), B. Siebert (PTB), J. Stenger (PTB), B.N. Taylor (NIST), A. Thompson (NIST), A.J. Thor (ISO/TC 12), A.J. Wallard (Director of the BIPM), Zhonghua Zhang (NIM).

Invited: Ch. Bordé (Académie des Sciences, Paris, IUPAP), R.S. Davis (BIPM), J. Fischer (PTB), M. Gläser (PTB), J. Kovalevsky (Honorary member of the CIPM), M.J.T. Milton (NPL), P. Richard (METAS), M. Stock (BIPM), R.I. Wielgosz (BIPM), T.J. Witt (BIPM) B. Wood (NRC, CODATA).

Also present: P. Giacomo (Director Emeritus of the BIPM); D. Le Coz, J. Miles, and C. Thomas (Executive Secretary of the CCU) from the BIPM.

Excused: R. Kaarls (invited, CIPM), E.R. Williams (invited, NIST), and Zhao Yan (invited, AQSIQ).

Prof. Mills opened the 18th meeting of the CCU noting that this was a large group of people. He then welcomed the new comers and the invited guests, especially Prof. Bordé and Prof. Kovalevsky, members of the Working Group of the French Academy of Sciences on base units and fundamentals constants (as well as Prof. M. Himbert, Dr T.J. Quinn, and Dr C. Thomas) and participants.

Dr Flowers was appointed Rapporteur. Mrs Le Coz and Ms Miles took notes during the discussions.

The agenda was then approved.

2 REPORT ON THE 8th EDITION OF THE SI BROCHURE

The president reported on the fact that since the 17th meeting of the CCU the new 8th edition of the SI Brochure has been published. After a final editing meeting held in Reading in February 2006, at which Terry Quinn, Barry Taylor, Anders Thor, Ian Mills and Claudine Thomas were present, it was

* For the list of acronyms, click here.

finally published in May 2006, on World Metrology Day. It is made up of 180 pages, the first 90 being the French text and the next 90 the English text. The new edition includes many revisions since the previous edition, and a new and extended Chapter 5 on how to write the symbols for quantities and units and how to express the values of quantities in the recommended format.

The Brochure has three appendices. Appendix 1 is a complete record of all the decisions of the CGPM and the CIPM related to the International System of Units (SI) since the first General Conference on Weights and Measures (CGPM) in 1889. These are presented in chronological order, with an index to allow easy location of particular topics.

Appendix 2 consists of the *mise en pratique* for the practical realisation of the definitions of some of the most important units. This is only available from the BIPM website, to allow for more frequent up-dating than is required for the rest of the Brochure.

Appendix 3 is a short summary on units for photochemical and photobiological quantities.

The 8th edition of the SI Brochure is also accompanied, for the first time, by the 4-page **Concise Summary** of the SI. This is available in both English and French, in order to provide a brief guide to the SI for those who do not require the full Brochure.

Finally there is a wallet-sized "micro-brochure", which unfolds to a single A4 size page with the key features of the SI. This is only available in English.

A copyright agreement covering redistribution, authorised translations, and re-branding of these publications is available from the BIPM. A Japanese version of the Brochure has already been authorised, and many more translations are in preparation. Dr Prieto informed the meeting that a Spanish version is in preparation.

There was discussion about the consistency of the format of Appendix 2, since each *mise en pratique* is prepared by the appropriate Consultative Committee (CC) and they are often in different styles. It was agreed that Prof. Wallard and Prof. Mills should take on the task of seeing that they all have a common and appropriate format.

It was agreed that the "adopted constants" $K_{J\text{-}90}$ and $R_{K\text{-}90}$, and the associated quantities V_{90}, A_{90}, Ω_{90}, etc., which are introduced in Appendix 1, should not be listed as units. They are physical quantities, introduced by CODATA, and may be described as "conventional quantities" used for expressing the results of electrical measurements based on the Josephson and quantum Hall measurements.

3 REVIEW OF REPORTS FROM OTHER CONSULTATIVE COMMITTEES AND OTHER GROUPS

The CIPM Recommendation 1 (CI-2005) asked other Consultative Committees and other groups to prepare reports for the CIPM, and for the CCU at this meeting, on possible changes to the SI. These particularly concern re-definitions of the base units. The meeting included a number of invited participants from these other bodies who were able to present and comment on their reports. The

President put this discussion into a historical context, saying that the idea of a unit system based on physical constants and atomic invariants was proposed by James Clerk Maxwell in 1870, yet the kilogram in particular is still defined in terms of an artefact manufactured in the 1880s.

3.1 Report of the Consultative Committee for Electricity and Magnetism, CCEM
(presented by Dr Wood)

The CCEM favour a definition of the kilogram and the ampere that fixes the values of e and h. This is because of the particular benefits this will bring to electrical metrology, by allowing the electrical units to be based on exact values of the constants $2e/h$ and h/e^2, which are used in the expressions for K_J and R_K in the Josephson and quantum Hall effects.

Prof. Bordé expressed his preference for a system based on a fixed value of μ_0 and Z_0. He noted that the change would be very small, since μ_0 and Z_0 are related through the fine structure constant α, which is now known with a relative standard uncertainty of only 7×10^{-10}. Dr Wood did not agree, saying that the Josephson effect volt gave an uncertainty of 3×10^{-10} at present, with a potential for further significant improvement, and that this would be compromised by a Z_0 based definition.

Prof. Bordé also remarked that the definition should include a statement of what the elementary charge is. Prof. Mills agreed, but asked that detailed discussion of the precise wording of new definitions should be postponed to a future meeting, advising that our task at this meeting should be to decide the principles on which any new definitions are to be based.

Prof. Bordé observed that the Josephson and quantum Hall relations, $K_J = 2e/h$ and $R_K = h/e^2$, are likely to have small further corrections similar to those that apply to the relations for the energy levels of the hydrogen atom. Dr Taylor observed that no such correction terms have been discovered after, in the case of the Josephson effect, 40 years of investigation. Dr Flowers pointed out that the SI relies on many relationships of physics, which could in future prove to have small correction terms. He also observed that if such correction terms are discovered they could be incorporated into the system at a later date. Dr Taylor added that the relation $E = mc^2$ was only recently verified at 4.4 parts in 10^7. Dr Newell pointed out the Biot-Savart law, the basis of the present ampere definition, was not as thoroughly experimentally verified as the Josephson relationship. It should be noted that Prof. Bordé maintained his view, saying that he believed there is a hierarchy of formulae in physics, where some are more deeply entrenched than others.

At the end of this discussion the vast majority of those at the meeting were in favour of a new definition of the ampere to fix e, rather than the present definition to fix Z_0 and μ_0.

3.2 Report of the Consultative Committee for Mass and Related Quantities, CCM
(presented by Dr Richard)

The CCM have made two recent (2005) recommendations, one on “Conditions for a new definition of the kilogram”, and one on “Preparative steps towards new definitions for the kilogram, ampere, kelvin and mole in terms of fundamental constants”.

The CCM have formed a working group on the silicon crystal density realisation of the kilogram, and their document is CCU/07-14. The CCU noted that in this document they gave the following criteria for redefining the kilogram:

- three independent experiments, one of them being the Avogadro experiment, giving results for the relevant constants with uncertainties less than 5×10^{-8}; at least one of these should have a relative standard uncertainty of 2 parts in 10^8;
- agreement between the Avogadro and watt balance experiments at the 95 % level of confidence;
- agreement on a *mise en pratique* to allow dissemination of the definition with continuity at the present level of stability.

They consider the choice between a definition based on the Avogadro or the Planck constant to be equivalent in their effect on mass metrology. They recommend two new task groups, one to review air or inert-gas to vacuum transfer, and one to assist the BIPM in documenting the uncertainty component due to traceability to the international prototype of the kilogram (IPK).

Dr Mohr asked for clarification of the current uncertainty in the mass of the IPK. Dr Davis said that this was currently estimated as 5 μg based on the instability of the working standards. Dr Taylor observed that this takes no account of the uncertainty due to the drift in the mass of the IPK, and of all the platinum iridium mass standards, over the last hundred years since they were made, although it is expected to exist.

Dr Siebert pointed out that the "confidence level" is not a well defined concept for such a small number of results. It was accepted that the results would have to be considered individually to determine confidence in the agreement, as is done in the CODATA reviews. Dr Taylor observed that if the recommendation of the CCM is taken literally, then if the Avogadro experiment fails to produce an acceptable result we would never go forward. Dr Richard and Dr Gläser agreed that the criteria presented could be reconsidered at a later date.

There was some discussion of the chosen value of uncertainty in the realisation of the kilogram following redefinition. Although it was agreed that 2 in 10^8 suggested by the CCM was a reasonable value, some members felt it was too cautious. Suggestions ranged between 2 and 5 parts in 10^8, but there was no consensus on fixing an exact value. Prof. Mills summed up the discussion saying that we all agree that the discrepancies must be resolved, but that we do not need to agree now on the exact level of uncertainty required.

The need for watt balance realisations after a redefinition was discussed. Dr Quinn suggested that no watt balance measurements will be needed immediately after redefinition since prototype masses are stable enough for 10 to 15 years. Then another absolute realisation could be made. Several members pointed out that although this may be the case in principle, continuity of experimental effort was needed in practice and multiple experiments were preferable to ensure reliable data.

3.3 **Progress on the international Avogadro experiment** (presented by Dr Fujii)

Dr Fujii reported on progress of the international Avogadro experiment. This involves eight NMIs, working to re-evaluate the Avogadro constant by the silicon crystal density experiment. They are

using an isotopically enhanced sample of silicon which is 99.995 % pure ^{28}Si, to reduce uncertainty from the imperfectly known abundance of ^{29}Si and silicon ^{30}Si. Other aspects of the experiment are also being addressed to reduce all contributions to the uncertainty. The target uncertainty in the result for the Avogadro constant is 2.1 parts in 10^8 (compared with 2.9 in 10^7 for the previous measurement and a 1 in 10^6 discrepancy with the watt balance measurement of h). 5.7 kg of the isotopically enhanced material has been produced, which will be sufficient for two spheres. The material is being sent to the NMIA for polishing. The final result is expected in 2010.

3.4 Discussion paper on "New definitions of the kilogram" (presented by Dr Gläser)

This paper, CCU/07-06, is a summary of the *Metrologia* paper of Becker *et al.* (*Metrologia*, 2007, **44**, 1-14). In this paper alternative definitions for the kilogram and the mole are discussed. Their preference is for a definition of the kilogram based on the mass of carbon 12, since they regard a definition based on the Planck constant as too obscure to be acceptable. They also suggest defining the SI volt by fixing the ratio h/e.

Prof. Mills expressed the view that it would be desirable not to change the present choice of seven base units, since this would probably not be welcomed by the members of the CGPM, and might indeed cause confusion in the world of metrology in general. He also observed that defining the second by fixing an atomic property, the hyperfine splitting frequency of the caesium atom $\Delta\nu_{HFS}$, and defining the metre by fixing a fundamental constant, the speed of light in vacuum c, has proved quite acceptable. The extension to defining other units in terms of fixed values of the fundamental constants is not so great a step. He reminded the meeting of the possibility of wording a definition to include both a statement of the fixed value of a physical constant and a more traditional statement in terms of a physical experiment, as suggested in document CCU/07-10.

Dr Wood asked if the suggestions of Mills *et al*. in their *Metrologia* paper would be acceptable to the mass community. Dr Gläser said that the CCM was neutral on the choice of definition for the kilogram, and that his presentation of a preference for the Avogadro definition represented only the views of the authors of the Becker *et al*. paper.

Dr Karshenboim argued that the scientific issues should override arguments about the desirability of a definition that is simple to comprehend. There followed a discussion about the difficulty of explaining a Planck constant based definition in simple words. However the general conclusion was that the best definition on metrological and scientific grounds should be chosen rather than compromising to make it easier to understand.

3.5 Report of the Working Group of the Académie des Sciences (presented by Prof. Kovalevsky)

There were five members of the Working Group of the Académie des Sciences at our meeting, including Prof. Kovalevsky, the chairman. Their report is document CCU/07-05.

In their report they express a preference for a definition of the kilogram to fix h (agreed by all members of the group), and they recommend that the change should not be made until the

discrepancy with the Avogadro result is resolved. They also recommend defining the ampere to fix q_p (this was a majority decision). A definition to fix q_p, the Planck charge, is equivalent to fixing μ_0, or Z_0, which is the current definition of the ampere. Dr Mohr asked whether the majority for fixing q_p was close. Prof. Kovalevsky said that it was a comfortable majority.

Prof. Bordé presented his view that it is preferable to fix q_p, μ_0, and Z_0, which he has also expressed in his paper CCU/07-17. There followed a further general discussion on the reliability of the relations $K_J = 2e/h$ and $R_K = h/e^2$. Prof. Bordé is of the opinion that further correction terms could be discovered, and that some physical relations were more soundly based than others. The more pragmatic view of the majority present was that such terms will be taken into account if and when they arise, but until then the relations can be taken as exact. The majority were clearly in favour of re-defining the ampere to fix e, rather than to retain the present definition to fix μ_0.

3.6 Report of the Consultative Committee for Thermometry , CCT
(presented by Dr Fischer)

A task group of the CCT has considered the proposed change in the definition of the kelvin to one based on a fixed value of the Boltzmann constant, in place of the present definition based on the temperature of the triple point of water. Their views are reported in CCU/07-12. They recommend that this change should go ahead in 2011, by when the outcome of a number of experiments currently in progress to improve the knowledge of k will be available. This change would neither require nor prevent any change to ITS-90.

The advantages of the new definition would be: it would no longer depend on the properties of a particular material, that is difficult to purify and that requires a specified isotopic composition; it would no longer be a definition specified at one particular temperature, but one that could be realised at any temperature; and it would be a definition expressed in terms of a fundamental constant.

In response to questions, Dr Fischer agreed that the redefinition could go ahead with only the present knowledge of k, with no loss – but perhaps little improvement – in the accuracy with which we could realise the kelvin. Prof. Mills reminded the meeting of our conclusion at earlier sessions that major changes to the SI would best be made all at one time. If the change in the kelvin were agreed but the change in the kilogram were still awaiting new data, then the change would best await resolution of the kilogram issue.

The explicit constant definition of the kelvin was preferred by the CCT, since it carries no assumption of the measurement method.

Dr Fujii expressed a concern of the Japanese committee on units about the practical implementation of temperature measurement, but was reassured by Dr Fischer that the ITS-90 will remain unchanged following the redefinition and will continue to be used in the same way.

3.7 Report of the Consultative Committee for Amount of Substance: Metrology in Chemistry, CCQM (presented by Dr Milton)

The recommendation of the CCQM is document CCU/07-11. Dr Milton also submitted his views in CCU/07-16. He feels that there is some confusion in the user community over the quantity amount of substance, and the unit mole. He favours – as does the CCQM – keeping amount of substance as a base quantity with its own dimension, and its own unit mole. However the $(1 + \kappa)$ factor is likely to cause confusion. There was an extended discussion of this problem. Prof. Mills and Dr Taylor expressed some regret about its introduction. Prof. Mills suggested that another paper clarifying the situation would be appropriate, for the benefit of the chemical community. Dr Wielgosz said that a group within the CCQM was working on such a paper. (Subsequent to this meeting Dr Taylor has submitted a clarifying paper, which is available as document CCU/07-22.)

3.8 Report of ISO/TC 12 (presented by Dr Thor)

This report is paper CCU/07-13. They recommend a definition of the kilogram related to the mass of a carbon 12 atom. Fixing the values of e, k and N_A to redefine the ampere, the kelvin and the mole were accepted. Dr Thor proposed that the kilogram and the kilomole should both be base units, and that they should both be given new names that do not include a prefix. The chairman curtailed a discussion of new names since this had been rejected at previous meetings. Dr Thor also proposed that the meeting should endorse his systematic view of the origin of a system of units as dependent on first defining a system of quantities. Dr Taylor and Dr Quinn both expressed reservations with the description of this in the introduction to CCU/07-13; this is an idealised view, and is not how things actually developed. Prof. Mills suggested that there is nothing wrong with the report, but that it was not appropriate to pursue formal adoption.

3.9 Report of IEC/TC 25 (presented by Prof. Borghi)

This report is CCU/07-15. IEC/TC 25 established an *ad hoc* working group to consider new definitions for the ampere, which has met twice over the last 12 months. All but one member of the group were in favour of a redefinition to fix the value of e.

3.10 Report form IUPAP (presented by Dr Mohr)

This report is CCU/07-19. Because there has been no significant interaction with the IUPAP commissions, this report is not a consensus but is largely the views of Dr Mohr and Prof. Bordé. The choice between fixing e or fixing Z_0 to redefine the ampere is an issue.

Dr Mohr presented his personal preference for fixing e because of the advantage it offers for fixing the values of the theoretical expressions for K_J and R_K. There followed further discussion of this issue, on which Prof. Bordé preferred the contrary view. In the end of the discussion Prof. Mills observed that although he had great respect for Prof. Bordé's views, it was clear that the feeling of the meeting was a preference for defining the ampere to fix e.

3.11 Report of the Consultative Committee for Photometry and Radiometry, CCPR
(presented by Dr Stock)

This report is CCU/07-18. Redefinition of the candela is being discussed, but is still considered to be far in the future. The necessary experiments to realise a quantum definition have still to improve by several orders of magnitude to allow a quantum definition of the candela.

4 PHYSIOLOGICAL QUANTITIES AND UNITS

Dr Quinn reminded the meeting of the importance of physiological quantities and units. He felt that this issue should be tabled for our next meeting. Prof. Wallard suggested that a cross-CC working group should be set up, with representation from the CCU, CCQM, and others. He undertook to work on this. Dr Stock said that it was the view of the CCPR that photometry was a special case of biological units and that the candela should remain as a base unit. In the ensuing discussion some members thought that candela belonged conceptually with other biological units, and that these should be in a separate section of the SI. Dr Stock said that lighting is an important industry which deserves special attention. Dr Milton said that the biological community was not clear on the issue of units, and that this was a big opportunity to open the door to that community and show them how to build a system of units. Prof. Wallard accepted that he should work to bring this about.

5 DRAFTING THE WORDS FOR REVISED DEFINITIONS OF UNITS

There was a general discussion on the form of words that should be used for new definitions. Although there was no general agreement, there was increasing support of a form of words based on the value of a fundamental constant fixed by the definition, although definitions should also include clarification in terms of a physical effect. Prof. Mills agreed that there were many complications in producing satisfactory wording and that this should be discussed at the next CCU.

6 THE DECIMAL MARKER

Dr Thompson reported that although the use of both the comma and point on the line as decimal markers had been accepted by ISO and IEC their staff are not implementing this in document publication. The CCU felt that this was unacceptable and a letter to the secretary general of ISO was drafted by Prof. Wallard and Prof. Mills, and approved by the meeting.

7 REPORT FROM THE CCU TO BE PRESENTED TO THE CGPM AT ITS 23rd MEETING IN NOVEMBER

Prof. Mills reviewed his conclusions as to what he should report to the CGPM at the meeting in November as follows.

- The only true invariants of nature that can be used to define the base units of the SI are the fundamental constants of physics or the properties of simple atoms. This is the subject of quantum metrology, and our objective should be to define all the base units of the SI in this way.
- Although it is clearly desirable to adopt simple definitions that are easy to comprehend, especially for non-experts in modern theoretical physics, the nature of modern quantum physics is such that this is not always possible. This problem may be to some extent alleviated by offering simple *mises en pratique* for the realisation of the definitions, and it is important to pay attention to this. However the fundamental principles of the definition of a base unit should be clearly distinguished from its realisation, which may often be achieved in a variety of different ways.
- The principles behind any new definition of a base unit may be conveniently summarised by stating which of the fundamental constants are fixed by each definition.
- All changes to the definitions of base units should be made to preserve continuity in the values of the constants concerned, by making use of the latest CODATA estimates of the values of the fundamental constants at the time of adopting any new definitions. Here “continuity” means that measurements made using the new definitions should agree with measurements made using the old definitions to the extent that the uncertainty of measurements allow.
- The actual words used to express the definition of a base unit may usually be formulated in a variety of different ways for the same definition. This is an important aspect of the definition. Although it is desirable to decide the principles of each definition as soon as possible if the new definitions are to be implemented in 2011 (as discussed at our meeting), the words used to express each definition require careful consideration, and do not have to be finally decided until perhaps 2009 for a change to be implemented in 2011.

- The meeting was unanimous in agreeing that a new definition of the **kelvin**, unit of thermodynamic temperature, should be adopted to fix the value of the Boltzmann constant k (or k_B). This would escape the dependence of the present definition on the properties of a particular material which is difficult to realise (pure water of a specified isotopic composition), and replace it by a definition referenced instead to a fundamental constant. If this change is made, k would become an exactly known constant, and the temperature of the triple point of water T_{TPW} would become an experimental quantity. The relative standard uncertainty in T_{TPW} if the change were to be made now would be 0.46 mK. This uncertainty in T_{TPW} would not significantly change the thermodynamic uncertainty in measurements of temperature on the International Temperature Scale ITS-90.
- Of the two alternative ways of defining the **kilogram** in terms of a fundamental constant, the meeting recognised that a definition in terms of the mass of a particle (such as the carbon 12 atom, which would fix the value of the Avogadro constant N_A) has the advantage of ease of comprehension. However a definition to fix the value of the Planck constant h is more closely related to modern quantum physics, is not dependent on an arbitrarily chosen particle, and has significant advantages for electrical metrology as discussed below. The feeling of the majority in the meeting of the CCU was clearly in favour of a **new definition of the kilogram to fix the Planck constant *h*** rather than the Avogadro constant N_A. There was also a clear feeling that a new definition of the kilogram should not be implemented until the present inconsistency between the XRCD measurements of N_A and the watt balance measurements of h has been satisfactorily resolved. The meeting wished to encourage all further experiments to better determine the values of the Planck constant and the Avogadro constant.
- The possible difficulty of comprehending a definition of the kilogram that fixes h would be mitigated by emphasising the intention that one way of realising the new definition will be to maintain one or more mass standards at the BIPM as references whose values will be measured from time to time by a watt balance (or any other method linked to h directly). In this way the present close coordination of practical mass standards throughout the world will be maintained, but the unit of mass will be linked by the new definition to an invariant of nature, h, rather than to a prototype whose mass is known to be drifting with time. However there will be nothing to stop any laboratory at any time making its own direct measurement of mass using the new definition in the same way that it can directly realise the second or the metre at present.
- Regarding the definition of the **ampere**, the choice is between defining the ampere to fix the value of μ_0, and hence also ε_0, Z_0 (and q_P if h is fixed), leaving the elementary charge e to be determined experimentally, or defining the ampere to fix e, leaving either the constants μ_0, ε_0, Z_0 or the constant q_P to be determined experimentally. The CCU meeting was strongly in favour of a definition to fix the elementary charge e. The meeting felt that defining the kilogram to fix h and the ampere to fix e would be a significant advantage for electrical metrology, despite the possibility of small correction terms to the relations $K_J = 2e/h$ and $R_K = h/e^2$ being one day discovered.

- Regarding the definition of the **mole**, the CCU believes that it is important to retain the present situation in which 'amount of substance' is regarded as a base quantity with its own dimension, with the mole as the corresponding base unit. The CCU recommends a new definition of the mole to fix N_A in place of the present definition to fix the molar mass of carbon 12, $M(^{12}C)$. This would be simpler and thus desirable, and would have the advantage that the definition of the mole would no longer be dependent on the definition of the kilogram. The change would mean that the value of $M(^{12}C)$ would become an experimental quantity, but the uncertainty in its value would be only 1.4×10^{-9} which is so small that it would have no impact on chemical metrology.
- The CCU is not recommending any change in the present definition of the candela.

8 DATE OF NEXT MEETING

It was decided that it would be appropriate to hold a meeting in two years time, around June 2009. The main purpose would be to agree the form and wording of the new definitions, and *mise en pratique* for their implementation. We should thus plan to draft a revised chapter 2 of the SI Brochure, and we should work on this during the coming years. Prof. Mills will initiate the process in advance of the meeting by circulating documents.

Dr J. Flowers, Rapporteur

November 2007

APPENDIX U 1.
WORKING DOCUMENTS SUBMITTED TO THE CCU AT ITS 18TH MEETING

Working documents submitted to the CCU at its 18th meeting are on restricted access.