EMRP Call 2011 - Health, SI Broader Scope & New Technologies

Selected Research Topic number: **SRT-s06**
Version: 1.0

Title: Realisation of the awaited definition of the kilogram - resolving the discrepancies

Abstract

The kilogram is the last unit in the International System still based on an artefact: the international prototype of the kilogram (IPK). The potential drift in the international prototype kilogram may cause instabilities in the SI and hence a redefinition of the kilogram is high on the international metrology agenda. A significant international effort is under way to establish a new definition based on fundamental constants, and a large consensus currently exists to link the kilogram to the Planck constant *h*. In order to achieve a redefinition a coherent realisation of the kilogram based on different experiments is required. Up to now, Planck-constant measurements based on the watt-balance and the Si-sphere Avogadro experiments have been completed, but the results show discrepancies which impair a realisation to within the required relative uncertainty of 2×10^{-8}. The proposed JRP should deliver improvements on these experiments with the aim of resolving the discrepancies, thus enabling the redefinition of the kilogram.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on “Grand Challenges” related to Health, New Technologies & Fundamental Metrology on pages 26 and 27.

Keywords

Mass metrology, new definition of the kilogram, watt balance, Planck constant h, molar Planck constant, Avogadro constant, silicon spheres, kilogram realisation, international-prototype drift, electrical units

Background to the Metrological Challenges

Today, the kilogram is the last unit of the International System of Units (SI) still based on an artefact. Since 1889, mass metrology has relied on the International Prototype of the Kilogram (IPK) which has by definition a mass of exactly 1 kg. Long term drift between the IPK and the official and national copies has been identified by 3 international mass comparisons over the last 120 years to be as large as 50 µg (i.e. $5 \cdot 10^{-8}$).

A significant international effort is under way worldwide to establish a new definition based on fundamental constants, and it is now commonly accepted that the new definition of the kilogram will be based on a fixed numerical value of the Planck constant *h* based on the CODATA (Committee on Data for Science and Technology) adjustment of fundamental constants [1, 2].

Two different experimental approaches are being pursued, firstly the watt balance experiment which is based on the equivalence between virtual electrical and mechanical powers and links the kilogram to a fundamental constant through the electrical quantum standards and secondly the X-ray crystal density method (Avogadro project) which determines the Avogadro constant (N_A) through the measurement of the macroscopic and the microscopic densities of a single crystal silicon sphere.

The fundamental and mandatory condition in order to achieve a redefinition is a coherent realisation of the kilogram based on different experiments. A redefinition of the mass unit should not introduce additional uncertainties into the dissemination chain nor should it affect the present system of accuracy classes of mass standards.

EURAMET, EMRP-MSU
National Physical Laboratory
Hampton Road, Teddington,
Middlesex, TW11 0LW, UK

Phone: +44 20 8943 6666
emrpA169@npl.co.uk
www.euramet.org

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In order to ensure the continuity of the mass scale, the Comité Consultatif pour la Masse et les Grandeurs Apparentées (CCM) recommended that the following conditions need to be met before the kilogram is redefined:

- At least three independent experiments, including work both from watt balance and from International Avogadro Coordination projects, yield values of the relevant constants with relative standard uncertainties not larger than 5 parts in 10^8. At least one of these results should have a relative standard uncertainty not larger than 2 parts in 10^8.
- For each of the relevant constants, the values provided by the different experiments be consistent at the 95% level of confidence.
- Traceability of BIPM prototypes to the international prototype of the kilogram be confirmed.

Currently the level of agreement from the various watt balance and Avogadro determinations and the uncertainties of the individual results are not sufficient to meet the requirements above and work is required to resolve the discrepancies and reduce the uncertainties.

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP-Protocol.

The JRP shall focus on resolving the existing discrepancies between independent experiments for the new definition of the kilogram including results both from different watt balance experiments and from the Avogadro project and demonstrate conformity with relative standard uncertainties not larger than 5×10^{-8}.

The specific objectives are

1. To identify the key parameters for comparisons to resolve the discrepancies and establish the methodology
2. Perform comparisons, analysis and identify the key reasons for the discrepancies
3. Based on the findings, fine-tune and adjust the existing European watt balances to their maximum performance level
4. Determine the Planck and Avogadro constants involving new comparisons against the International Kilogram Prototype
5. Demonstrate the consistency, repeatability and stability of the watt-balance (including the NIST experiment) and Avogadro methods.

The last objective is optional since the requirements for it may be beyond the capabilities provided by a JRP. The proposed JRP should include all relevant experiments contributing to the proposed new definition of the kilogram.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this, including progress beyond the previously funded EMRP projects:

- T1 J1.1 e-MASS: The watt balance route towards a new definition of the kilogram
- T1 J1.2 NAH: Avogadro and molar Planck constants for the redefinition of the kilogram

The total eligible cost of any proposal received for this SRT is expected to be around the 2.7 M€ guideline for proposals in this call.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

You should detail other impacts of your proposed JRP as detailed in the document “Guide 4: Writing a Joint Research Project”

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the CIPM, CGPM, Consultative Committees, the international NMI/DI community and the BIPM
- transfer knowledge to the Committee on Data for Science and Technology (CODATA)
- effectively link to the watt balance experiments conducted in North America ie at NIST and NRC.

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.

The CGPM (Conférence Générale des Poids et Mesures) is the authority responsible for decisions to change the definitions of the SI. The time scale is defined by the international context, in particular the CGPM meeting in 2015 at which date the decision will probably be taken to change the kilogram definition. New measurement results for the Planck and Avogadro constants are required for inclusion in the 2015 CODATA adjustment.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] I. M. Mills, P. J. Mohr, T. J. Quinn, B. N. Taylor, and E. R. Williams. “Redefinition of the kilogram: a decision whose time has come”, Metrologia, 42:71-80, 2005.

[2] Resolution 12 of the 23rd meeting of the CGPM; “On the possible redefinition of certain base units of the International System of Units (SI)”