Getting Closer to Redefining The Kilogram

International prototype kilogram at the BIPM

by Dr. Zeina J. Jabbour

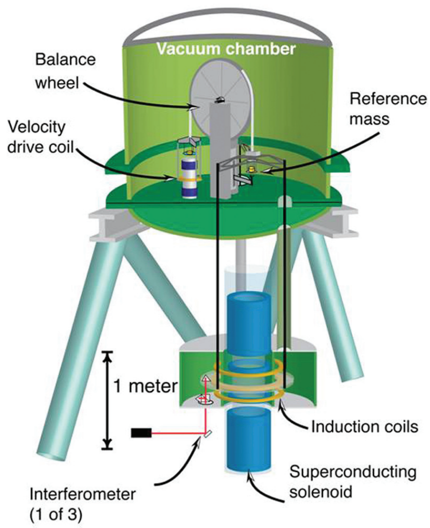
A redefinition to replace the last remaining artifact–based unit of the International System of Units (SI), the kilogram, may occur as early as 2011. This article presents a short summary of the status of current international efforts focused on the redefinition and the internationally agreed upon requirements for the redefinition of the mass unit.

Brief History

The kilogram is the last remaining base unit of the International System of Units (SI) defined by an artifact; its current definition dates back to 1901 and simply states[1]: "The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram."

The international prototype of the kilogram (IPK) is a cylindrical artifact with height nearly equal to diameter (39 mm), made of a 90 percent platinum and 10 percent iridium alloy and kept at the Bureau International des Poids et Mesures (BIPM) in France. Copies of the IPK were manufactured, calibrated with respect to IPK, and either distributed to members of the Meter Convention to serve as national prototypes or kept at the BIPM as official copies of the IPK or as working standards. In addition to the danger of being damaged or destroyed, the IPK suffers from long-term instability relative to the BIPM official copies and national prototypes as documented in the results of the third periodic verification of all the national prototype kilograms[2]. In order to eliminate the problems associated with an artifact-based definition, the kilogram must be redefined with respect to a constant of nature. Two independent experiments are currently leading the efforts for a redefinition: the watt balance [3] and Avogadro [4] experiments.

Realization of the kilogram using either of the above experiments can now be obtained with enough precision and accuracy to raise realistic expectations of a possible redefinition in the near future. In the last few years there has been much discussion about when and how the redefinition of the kilogram should proceed[5-7]. A number of Consultative Committees for the International Committee for Weights and Measures (CIPM) have met and reported their opinions. With this information the CIPM has recommended that preparative steps towards new definitions of the kilogram in terms of fundamental constants be taken, and the meeting of the Conference Générale des Poids et Mesures (CGPM) in 2011 was set as the target date[8]. This date is contingent on the relevant experiments achieving both consistency and sufficient accuracy.



Schematic diagram of the NIST watt balance

The following sections present a short summary of the current status of the watt and Avogadro projects, and the requirements for a redefinition as set by the CIPM and its Consultative Committees.

Current Status

The watt balance experiment, also known as the electronic kilogram, relates the kilogram to Planck's constant. This is accomplished by balancing the weight of a 1 kg mass artifact with an electrical force generated by passing a current through a coil in a magnetic field and measuring it with respect to the Josephson volt and the quantum Hall resistance. The longest running watt balance experiments are at National Physical Laboratory (NPL) in England and the National Institute of Standards and Technology (NIST) in the United States. The published values of the relative standard uncertainties of the NIST and NPL experiments are 3.6 $\times 10^{-8}$ (36 µg/kg) and 6.6 $\times 10^{-8}$ (66 µg/kg), respectively, while the relative discrepancy between the results of

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the two experiments is 3×10^{-7} (300 µg/kg)[9, 10]. New results are expected from NPL based on modifications and improvements made to their watt apparatus in December 2008 before discontinuing the experiment and transferring its ownership to the national metrology institute in Canada in 2009[11]]. In the last decade, new watt balances have been developed at the national metrology institutes in Switzerland and France and at the BIPM; results are expected in the next few years.

The x-ray crystal density method (XRCD), also known as the Avogadro project, measures the kilogram with respect to Avogadro's constant or to an atomic mass by comparing the microscopic and macroscopic properties of a 1-kg silicon sphere. This project relies on a large international collaboration, International Avogadro Coordination project (IAC), in order to combine all of the resources needed to manufacture a "nearly perfect" 1-kg sphere of natural silicon and to measure its critical parameters such as mass, volume of sphere, volume of unit cell, isotopic purity, and molecular mass. The latest published results reveal a 3.1×10^{-7} (310 µg/kg) relative standard uncertainty and an unresolved 1.1×10^{-6} (1100 µg/kg) relative discrepancy with respect to the NIST watt balance result[4, 9]. Recent communications with the Avogadro group indicate the discovery of a correction to the published result that brings it into agreement with the result from the NIST watt balance. In addition, the IAC has succeeded in producing a single isotope silicon sphere and measuring the same critical parameters mentioned above. Final results on the Avogadro project's realization of the kilogram definition based on the single isotope silicon and the corrected values of the natural silicon result are expected by 2009 year-end[11].

Requirements for the Redefinition

The discrepancies between different experimental realizations of a new definition of the kilogram led to international debates to assess and establish the basic requirements for a redefinition of the unit of mass. These discussions were held at meetings of the Consultative Committees of the CIPM. The Consultative Committee on Mass and related quantities (CCM) recommended (1) resolving the discrepancy between the watt and Avogadro results, (2) that relevant experiments attain a relative standard uncertainty of approximately 2×10^{-8} (20 µg/kg) in order to prevent any negative impact on practical mass metrology, and (3) to develop methods for the practical realization of the new definition. The CGPM will consider a new definition in 2011 based on the available results at the time[8]. The CCM organized a special working group and task groups to establish accepted practical realization methods to link the new definition realized from the watt or Avogadro experiments to mass standards that will be used in the dissemination of the unit of mass. These groups will also evaluate the uncertainties associated with this process and resolve any other problems that might result from the implementation of the new definition.

About the Author

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