Redefinition of the Kilogram

SI – a universal language of measurements

The International System of Units (SI) constitutes a coherent set of units by which any measurable quantity of interest in research, industry, trade or society can be quantified. The signatory states of the Metre Convention represent about 98% of the world's economy, so the SI is the very basis of international trade and supports the global measurement quality infrastructure through national metrology institutes.

The international measurement community, through the International Committee for Weights and Measures, is presently working on updating the SI. This update, which will most probably occur in 2018, will redefine the kilogram, the ampere, the kelvin, and the mole in terms of fundamental physical constants.

The kilogram – the SI unit of mass

The kilogram, presently defined by the mass of the international prototype kilogram (IPK), will be defined by assigning an exact numerical value to the Planck constant. The Planck constant is a fundamental constant of nature and will allow the kilogram to be realized in terms of very accurate quantum electrical standards or by counting atoms, these experiments are outlined below. This redefinition will ensure a long-term stability and traceability of the unit for mass by making it independent of the material artefact. This modification will make the unit of mass independently realizable with a range of different experiments.

Methods to realize the kilogram

For the redefinition of the kilogram to be effective and to ensure minimal impact on the end-user community (discussed below) the Consultative Committee for Mass and Related Quantities (CCM) has recommended an uncertainty of 2 parts in 10^8 be reached by at least one realization method[1]. The current methods which can reach this uncertainty are the Kibble balance (formerly known as the watt balance) and the X-Ray Crystal Density (XRCD) methods. (These are the experimental methods being used at present to determine the value of the Planck constant to the target uncertainty. It is this value that will become exact to redefine the kilogram.)

The Kibble balance will determine the mass in kilogram of a test object from the exact value of the Planck constant by equating mechanical and electrical power. This requires precise measurements of voltage, resistance, length and time. The quantum electrical standards used to measure voltage and resistance link the mass of the test object to the fixed value of the Planck constant. The XRCD experiment relies on the precise relationship between the Planck constant and the mass of a silicon-28 atom. The kilogram is then realized by determining the number of atoms in a near-perfect sphere of pure, single-crystal silicon-28. This number is the ratio of the volume of the sphere, determined from length measurements, to the effective volume of a single atom in the crystal, determined from X-rays. The crystal may then be used to determine the mass of a test object. In practice, both

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[1] CCM RECOMMENDATION G 1 (2013) On a new definition of the kilogram

methods are more complicated than these simple explanations but further details can be found in other publications.

Making sure the realizations agree

To ensure the continuity of the SI unit of mass before and after the redefinition—that is, to ensure that the kilogram used after the redefinition is consistent with the kilogram used today—and to ensure international equivalence afterwards, the periodic comparison of realization results with each other, and initially also with the IPK, will be necessary. A pilot study to compare realization methods has been completed and periodic Key Comparisons will be organized in future to ensure the ongoing equivalence of the mass scale around the world.

Future benefits of the redefinition of the kilogram

In addition to ensuring the long-term stability of the SI unit of mass, defining the kilogram in terms of a physical constant will improve access to the mass scale by making possible geographically distributed realizations. In addition, the unit of mass can in principle be realized at any arbitrary mass without the need for traceability to a standard having a nominal value of 1 kilogram.

Realizing the benefits of the changes to the definition of the kilogram

A redefinition of the kilogram will remove the need for traceability to single artefact, whose mass is not inherently constant over time but which nevertheless has defined the the kilogram, since 1889. This definition of the kilogram can only be realized at a single geographical location. There are also the inherent problems of access, the IPK being used very rarely because its mass can change with use. However, to fully realize the benefits of the new definition there need to be a sufficient number of laboratories to realize the definition, ideally distributed around the world and providing a range of nominal mass values. At present this requirement is not fulfilled and it is the task of National Measurement Institutes to address this issue through coordinate research programmes into practical means of realizing the mass scale with relation to the Planck constant at nominal values near the kilogram (as with the current implementations) but also at other values.

Changes to the SI will provide a springboard for future innovation

As described above an uncertainty of 2 in 10^8 has been recommended by the CCM as being acceptable for the redefinition of the kilogram and experiments around the world currently determining the value of the Planck constant are already working at this level and below. These experimental methods will be used to realize the kilogram after the redefinition. It is likely that there will be small iterative improvements in the accuracy with which the new kilogram can be realized and disseminated. In the short to medium term the real benefit will be felt by the ability to realize the mass scale at different nominal values, particularly in improvements to the accuracy and reliability with which micro and nano masses and forces can be realized. In the longer term, shop floor and in-process realizations of mass and force measurements with direct traceability to the SI will be possible making the coherence of the global metrology infrastructure more practical and robust.