Redefining the kilogram

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New research, published by the National Physical Laboratory (NPL), takes a significant step towards changing the international definition of the kilogram – which is currently based on a lump of platinum-iridium kept in Paris. NPL has produced technology capable of accurate measurements of Planck's constant, the final piece of the puzzle in moving from a physical object to a kilogram based on fundamental constants of nature. The techniques are described in a paper published in *Metrologia* on the 20th February.

The international system of units (SI) is the most widely used system of measurement for commerce and science. It comprises seven base units (meter, kilogram, second, Kelvin, ampere, mole and candela). Ideally these should be stable over time and universally reproducible, which requires definitions based on fundamental constants of nature. The kilogram is the only unit still defined by a physical artifact.

In October 2011, the General Conference on Weights and Measures (CGPM) agreed that the kilogram should be redefined in terms of Planck's constant (h). It deferred a final decision until there was sufficient consistent and accurate data to agree a value for h. This paper describes how this can be done with the required level of certainty. It provides a measured value of h and extensive analysis of possible uncertainties that can arise during experimentation. Although these results alone are not enough, consistent results from other measurement institutes using the techniques and technology described in this paper will provide an even more accurate consensus value and a change to the way the world measures mass – possibly as soon as 2014.

Planck's constant is a fundamental constant of nature which relates the frequency (colour) of a particle of light (a photon) to its energy. By using two quantum mechanical effects discovered in the last 60 years: the Josephson effect and the quantum Hall effect, electrical power can be measured in terms of Planck's constant (and time).

A piece of kit called the watt balance - first proposed by Brian Kibble at the National Physical Laboratory in 1975 - relates electrical power to mechanical power. This allows it to make very accurate measurements of Planck's constant in terms of the SI units of mass, length and time. The SI units of length and time are already fixed in terms of fundamental and atomic constants. If the value of h is fixed, the watt balance would provide a method of measuring mass.

Dr Ian Robinson, who leads the project at the National Physical Laboratory, explains how the watt balance works: "The watt balance divides its measurement into two parts to avoid the errors which would arise if real power was measured. The principal can be illustrated by considering a loudspeaker placed on its back. Placing a mass on the cone will push it downwards and it can be restored to its former position by passing a current through the speaker coil. The ratio of the force generated by the current is fixed for a particular loudspeaker coil and magnet and is measured in the second part of the experiment by moving the speaker cone and measuring the ratio of the voltage produced at the speaker terminals to the velocity of the cone.

When the results of the two parts of the experiment are combined, the product of voltage and current (electrical power) is equated to the product of weight and velocity (mechanical power) and the properties of the loudspeaker coil and magnet are eliminated, leaving a measurement of the weight of the mass which is independent of the particular speaker used."

Measurements of h using watt balances have provided uncertainties approaching the two parts in one hundred million level, which is required to base the kilogram on Planck's constant. Thanks to improvements highlighted in the paper published today, measurements at the National Research Council in Canada, which is now using the NPL equipment, look set to provide considerably greater accuracy.

Another set of data comes from NIST, the USA's measurement institute. Currently the watt balance at NIST is showing slightly different results and the differences are being investigated. If the results are found to be consistent, it will be the start of the end for the physical kilogram.

A Planck based kilogram would mean a universal standard that could be replicated anywhere at any time. It will also bring much greater long-term certainty to scientists who rely on the SI for precise measurements, or on h itself. The watt balance would provide a means of realising and disseminating the redefined unit of mass.

Dr Robinson concludes: "This is an example of British science leading the world. NPL invented the watt balance and has produced an apparatus and measurements which will contribute to the redefinition. The apparatus is now being used by Canada to continue the work, and we anticipate their results will have lower uncertainties than we achieved, and the principle is used by the US and other laboratories around the world to make their own measurements."

"This research will underpin the world's measurement system and ensure the long term stability of the very top level of mass measurement. Although the man on the street won't see much difference - you'll still get the same 1kg bag of potatoes – these standards will ultimately be used to calibrate the world's weighing systems, from accurate scientific instruments, right down the chain to domestic scales."

More information: The paper: Toward the redefinition of the kilogram: A measurement of the Planck constant using the NPL Mark II watt balance is published in *Metrologia*, the leading international measurement science journal, published by IOP Publishing on behalf of Bureau International des Poids et Mesures (BIPM).

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