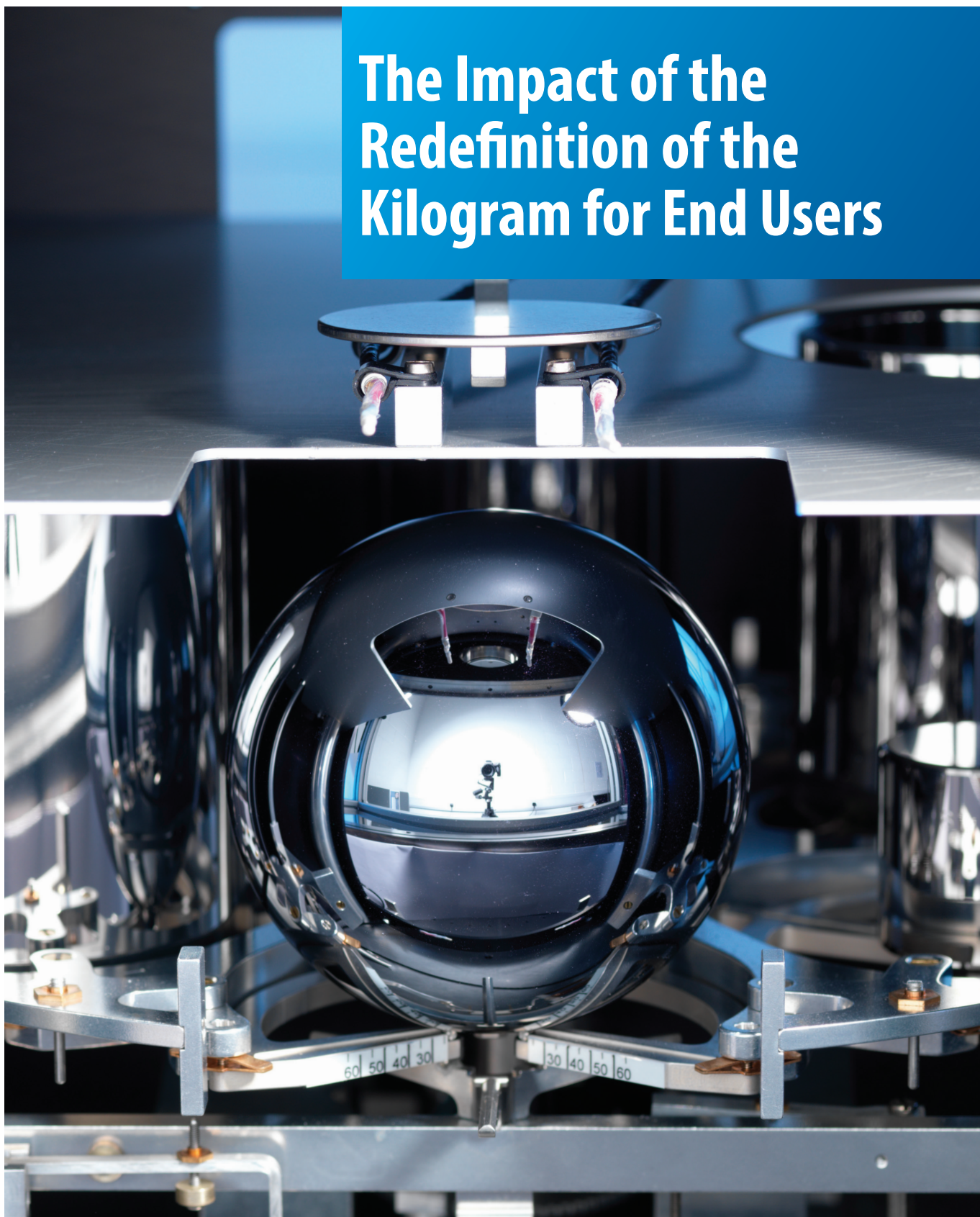


The Impact of the Redefinition of the Kilogram for End Users



The current kilogram

Of the seven SI base units, the kilogram is the only unit that is still defined by a physical artefact: the International Prototype of the Kilogram (IPK), a cylinder of platinum-iridium alloy. All measurements of mass must ultimately be traceable to the IPK, whereas the other SI base units have definitions based on fundamental constants and so can be independently realised by National Measurement Institutes (NMIs) and other laboratories. Presently the IPK represents a single point of failure for the mass unit: the mass scale is dependent on the stability of the IPK, which can change mass due to material loss and contamination from the surrounding environment.

The new definition

A definition of mass based on a fundamental constant would have the advantage of guaranteeing stability. The kilogram will be redefined in terms of

the Planck constant (h) in 2018 as part of a major revision of the SI base units. The definition of the kilogram will be revised to:

The kilogram, kg, is the unit of mass; its magnitude is set by fixing the numerical value of the Planck constant to be equal to exactly 6.626068×10^{-34} when it is expressed in the unit $\text{s}^{-1} \cdot \text{m}^2 \cdot \text{kg}$, which is equal to $\text{J} \cdot \text{s}$

The mass community can then, theoretically, be free to realise the kilogram, with relation to the Planck constant, using any suitable experiment.

Find out more:

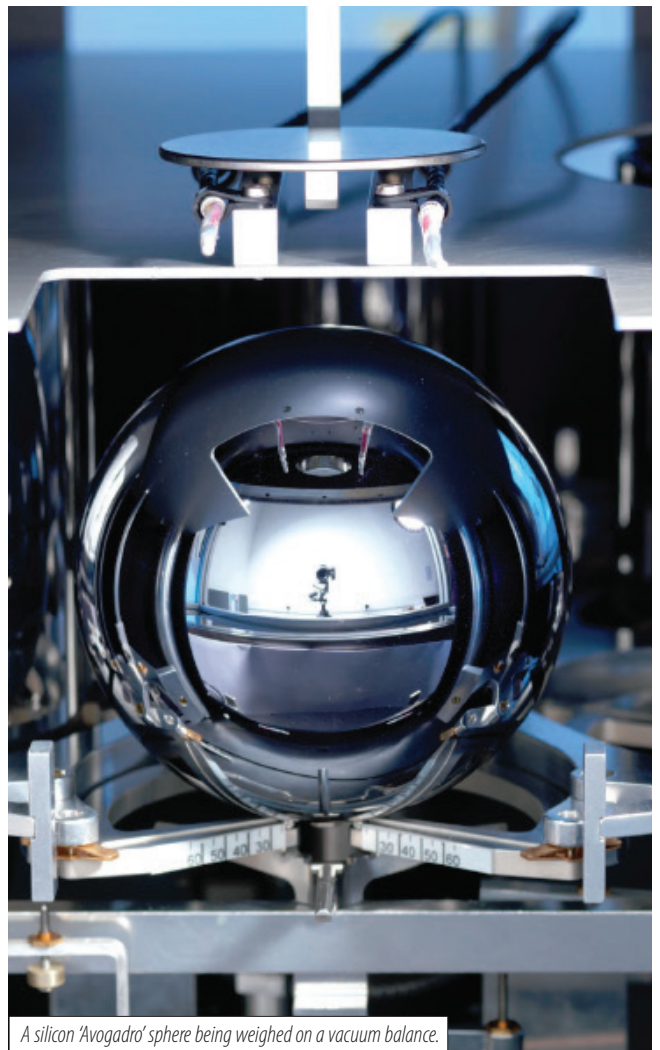
www.bipm.org/en/measurement-units/new-si/

Find out more:

www.bipm.org/en/bipm/mass/prototype.html



The International Prototype Kilogram stored under three bell jars at the Bureau International des Poids et Mesures.



A silicon 'Avogadro' sphere being weighed on a vacuum balance.

The primary realisation experiments

At present there are two key approaches being pursued internationally that can reach the accuracy required for the primary realisation of the kilogram (2 parts in 10^8 or 20 μg): the watt balance and the Avogadro (or X-ray crystal density) project.

The watt balance method, stems from an idea by Bryan Kibble of the National Physical Laboratory. He suggested using balance and a strong permanent magnet to compare mechanical and electrical power. Effectively, the experiment compares a force generated by the current in a coil sitting in a magnetic field with the weight of a mass.

The Avogadro project realises the kilogram in terms of Avogadro's number, which is equal to the number of atoms in 12 grams of carbon-12. The experiment involves determining the number of atoms in a single crystal of silicon in the form of a highly polished and extremely round sphere, by measuring the volume of the atomic unit cell and the overall volume of the sphere.

After the redefinition, either experiment can be used to realise the kilogram and the results should be equivalent.

Dissemination of the mass scale

The realisation of the kilogram via either the Avogadro or watt balance experiments, has two main implications for the dissemination of the mass unit in terms of traceability and uncertainty. At present, the uncertainty in the kilogram definition is zero since the value of the IPK exactly defined the kilogram. After the redefinition, the uncertainty will depend on the individual watt balance or Avogadro experiment used.



A set of stainless steel weights of OIML construction.

Currently the best uncertainty achievable is about 2 in 10^8 (20 μg on 1 kilogram) and this is unlikely to improve significantly before the redefinition in 2018.

Additionally, both the watt balance and Avogadro experiments operate in vacuum. In order to provide traceability to weights used in air, the effect of transferring mass standards between vacuum and air needs to be characterised, and the uncertainty of this additional link in the traceability chain needs to be fully assessed.

NEW KILO

NewKILO (www.newkilo.eu) is a collaborative joint research project between European NMIs. NewKILO has undertaken a range of research necessary to successfully implement the kilogram redefinition, to ensure the continuity of the SI unit and to provide the traceability to the redefined unit at the level of uncertainty required by the most demanding end users.

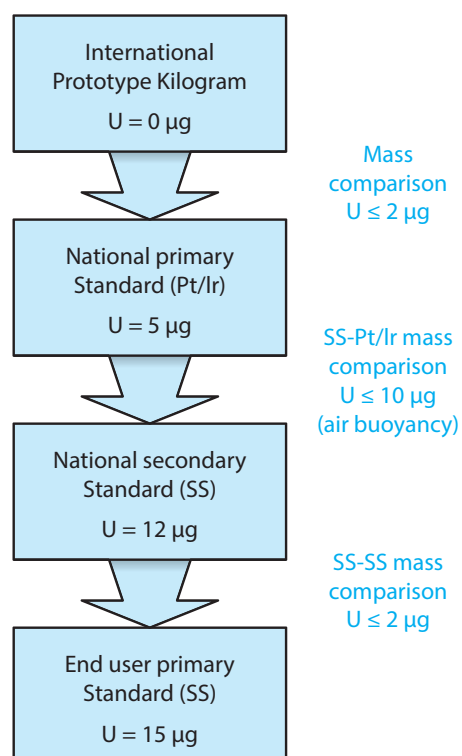
Areas of research have included the next generation of mass standards, suitable for use with primary realisation experiments; characterising the effect and uncertainty of air-vacuum transfer both gravimetrically and by surface analysis; and determining the most effective methods of cleaning and storing primary mass standards to optimise stability.

Uncertainties following the redefinition

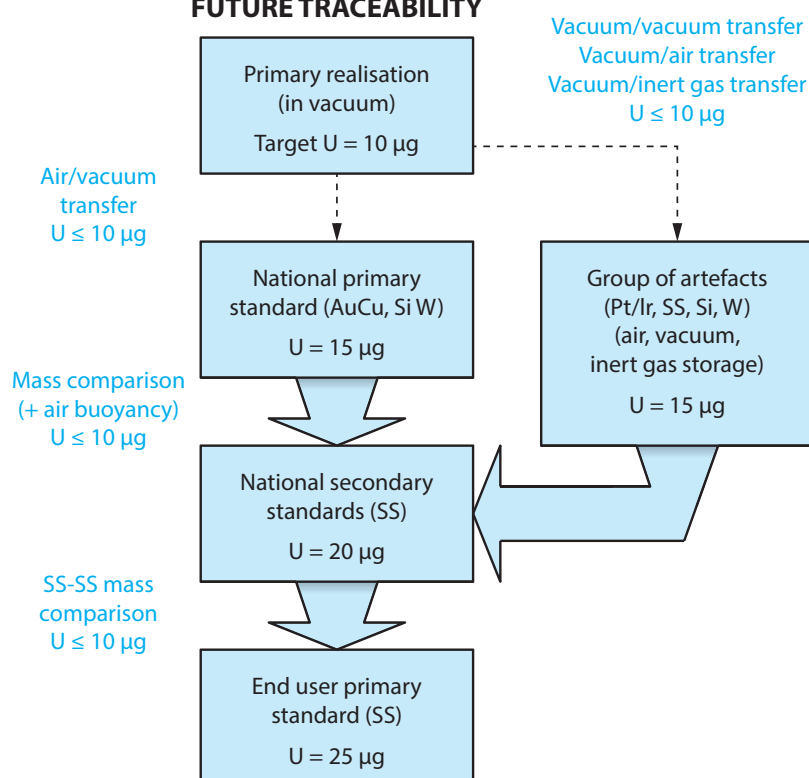
The current definition and realisation of the kilogram, and the relatively straightforward traceability chain, means NMIs are able to achieve Calibration and Measurement Capability (CMC) values (standard uncertainties) of the order of 15 micrograms for stainless steel kilogram mass standards; the major source of uncertainty being the effect of air buoyancy when comparing platinum-iridium and stainless steel weights.

After redefinition the standard uncertainty of the primary kilogram realisation experiments, at least initially, will be of the order of 20 micrograms. Add to this the uncertainty caused by the vacuum-air transfer necessary to achieve traceability and the uncertainties NMIs can provide to end users will inevitably increase immediately after redefinition. The diagram illustrates the sources and likely magnitudes of the standard uncertainties in question.

CURRENT TRACEABILITY



FUTURE TRACEABILITY



Impact

By 2018 there will be at least three independent experiments which will realise the value of the Planck constant with respect to the value of the IPK. This will give confidence that the value assigned to the Planck constant will be accurate and a suitable basis of the ongoing definition of the mass scale. Thus, the continuity of the SI unit of mass during the redefinition and the long term stability afterwards will be assured.

As outlined, the redefinition of the kilogram will have an effect on the uncertainties that can be provided by NMIs at the very highest level. However, the research undertaken by the NewKILo collaboration, among others, has ensured that the increase in this uncertainty will be minimised and improvements to the primary realisation experiments will reduce this uncertainty going forward.

Acknowledgements

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