Avogadro and molar Planck constants for the redefinition of the kilogram

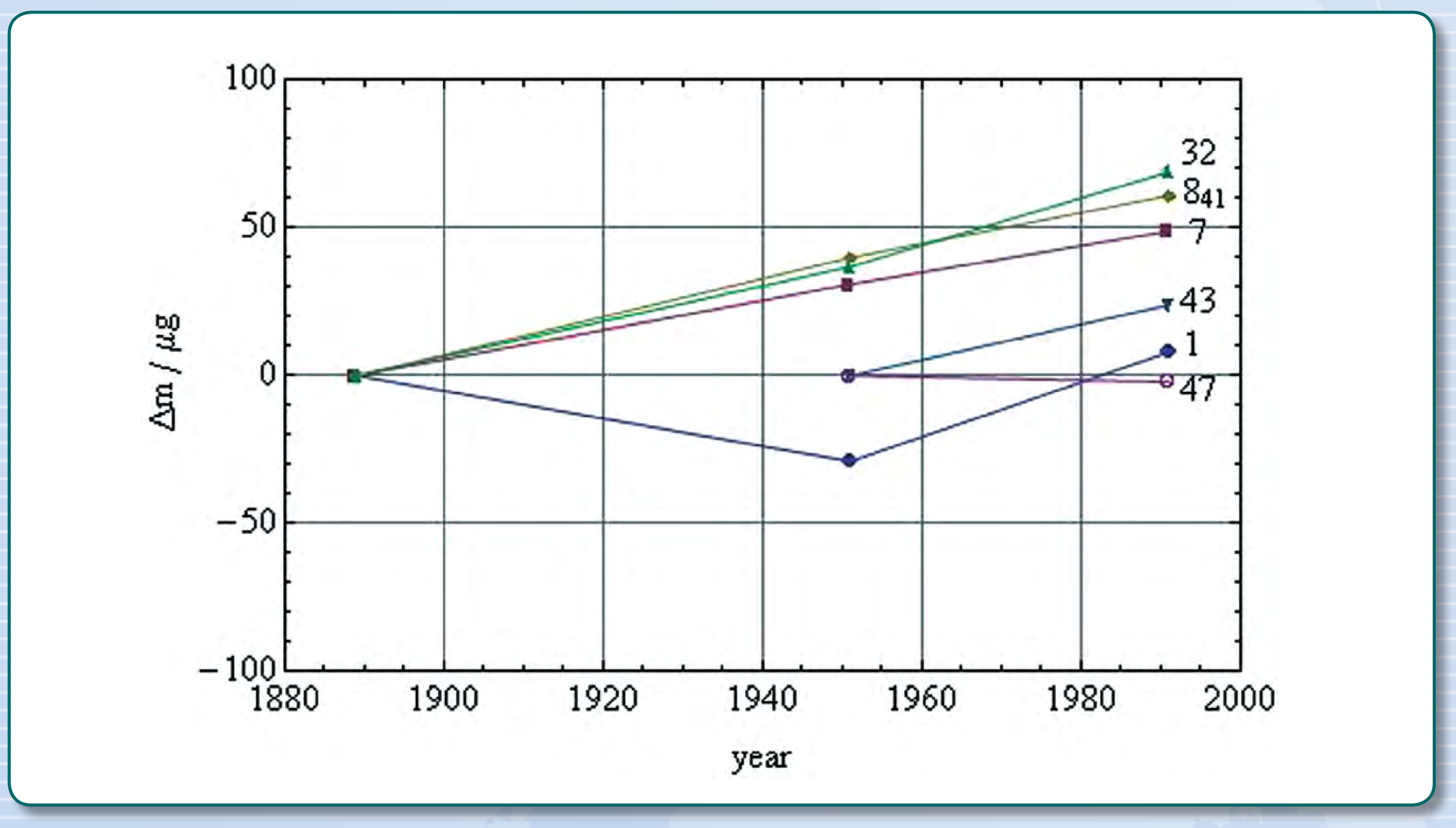
EURAMET
European Association of National Metrology Institutes

The need for the project

The kilogram is the only SI base unit to be defined by a material object - a Platinum-Iridium cylinder, kept at the Bureau International des Poids et Mesures (BIPM).

As a material object is vulnerable to its environment, the cylinder is changing as it ages and therefore a redefinition on the basis of a fundamental physical constant is needed.

The objective of this project was to link the mass unit, the kilogram, to the atomic mass unit via the Avogadro constant N_A, which specifies the number of atoms in one mole of substance. The project aims to demonstrate a direct kilogram realisation based on the mass of a silicon atom (isotope Si-28), expressed in terms of frequency and second. Determining the Avogadro constant in this way involves making measurements of the molar mass, volume, surface, density and lattice parameter.



Change in mass of the six official kg copies with respect to the mass of the international prototype.

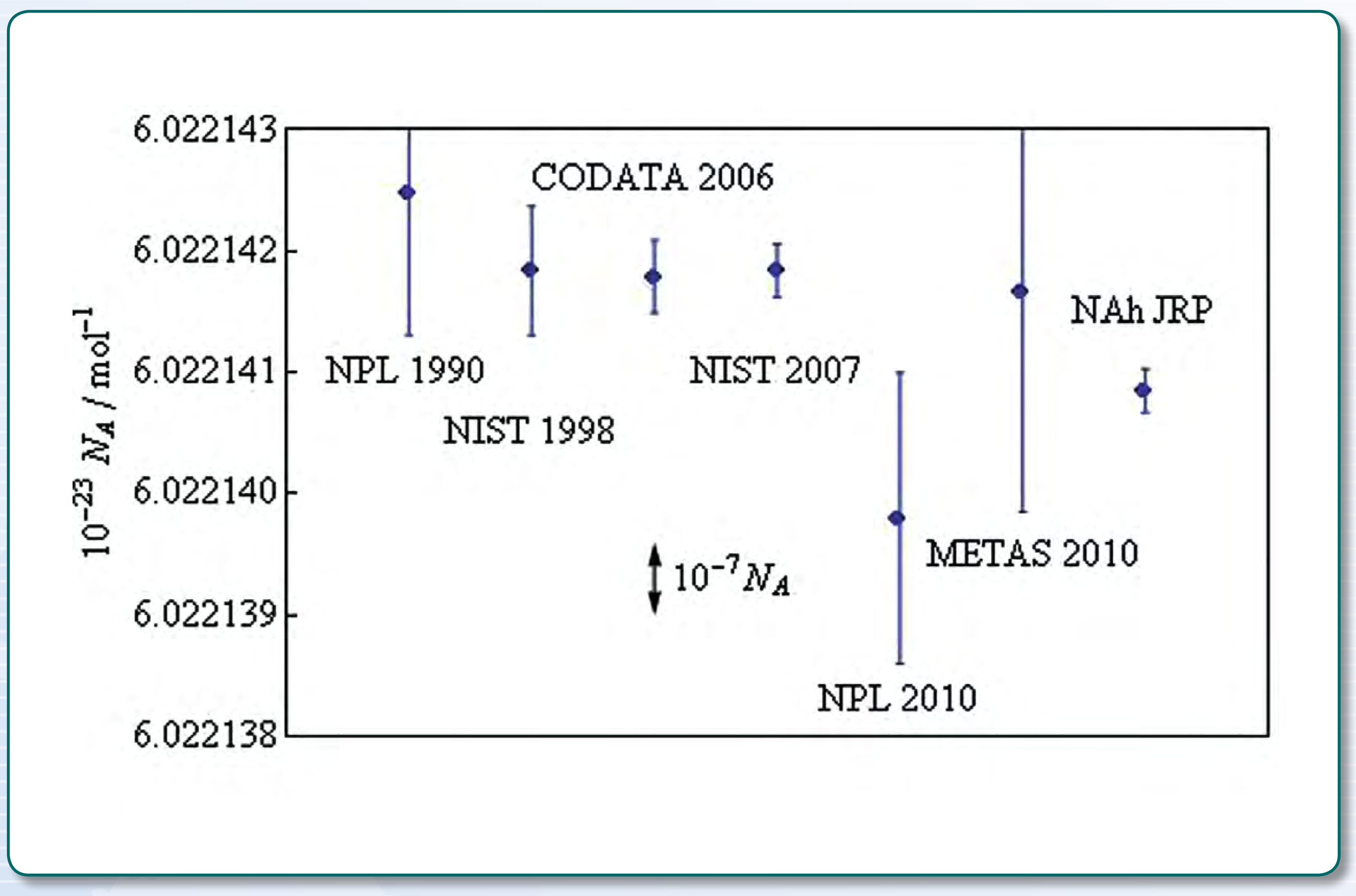
Technical achievements

Si-28 was purified to 99.99% (natural silicon contains around 92% Si-28) using centrifuges based at the Central Design Bureau for Machine Building in St Petersburg, Russia. This was then used to grow a crystal that was fashioned into two near-perfect spheres.

The enrichment relieved, but did not eliminate, the need to measure the isotopic composition of the crystal. This was done by means of mass spectrometry and by developing a novel measurement technique based on isotope dilution. Using laser interferometry and synchrotron radiation, each sphere's surface was mapped to measure its volume and to characterise its surface with atomic-scale accuracy. The crystal structure was imaged by x-ray interferometry to measure the atom spacing. The adequacy of crystal perfection and homogeneity to count the silicon atoms on the basis of their ordered arrangement in the crystal was also demonstrated.

By calculating the volume taken up by each atom, it was possible to work out how many atoms were in each sphere and, consequently, in a mole, $N_A = 6.02214082(18) \times 10^{23}\ \mathrm{mol}^{-1}$.

The present measurement uncertainty ($3 \times 10^{-8}\ N_A$) is 1.5 times higher than that targeted for a kilogram redefinition; it is limited by the performance of the measurement apparatus, not by crystal imperfection.



Comparison between the most accurate N_A values available. The bars give the standard uncertainty.

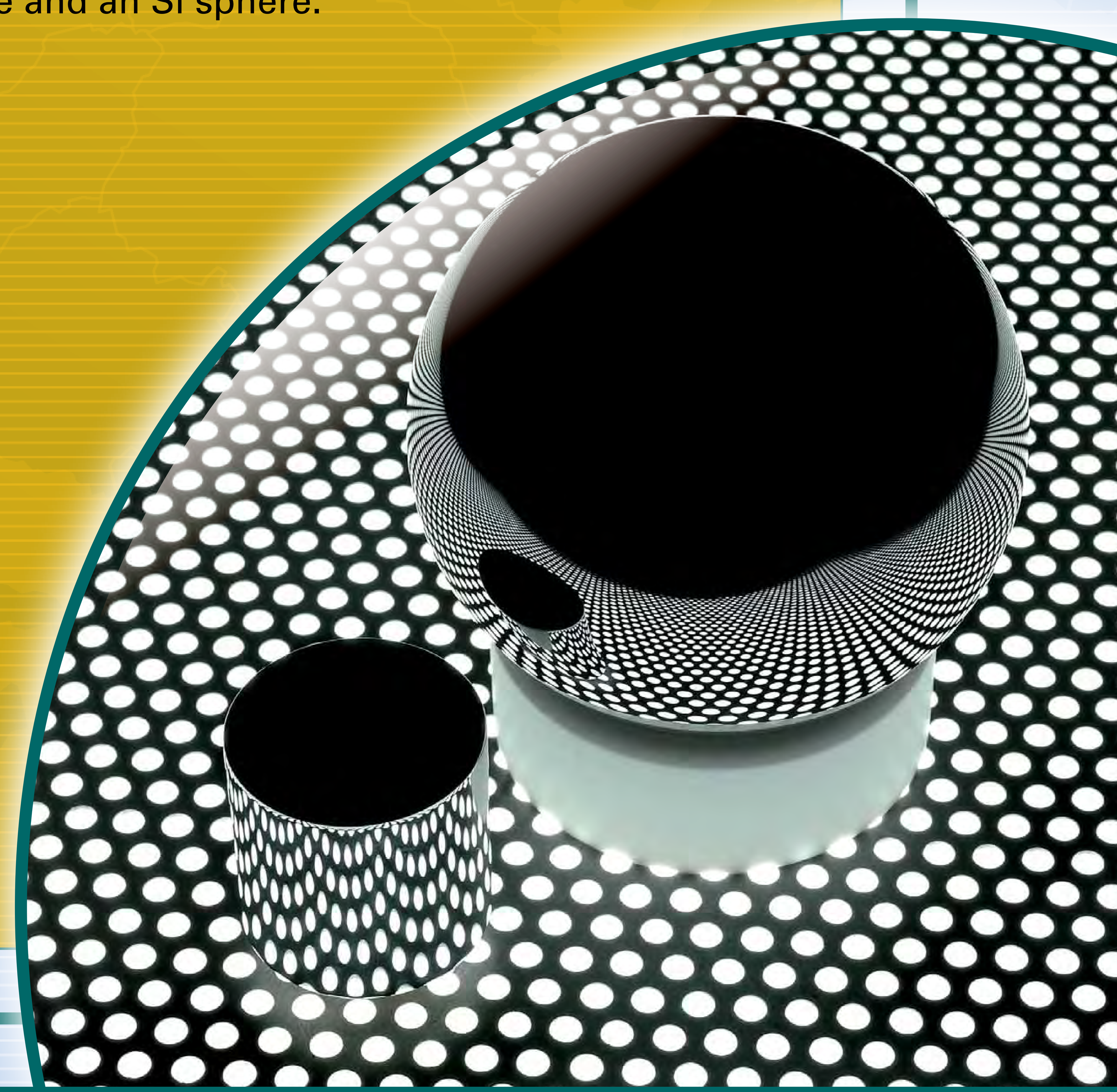
Redefining the SI units

Project results will be exploited by the Committee on Data for Science and Technology and the International Committee for Weights and Measures to improve the quality and reliability of data for science and technology and to redefine the SI units on the basis of conventionally agreed values of fundamental physical constants.

The Si-28 spheres will be used to demonstrate the kilogram based on a fixed value of the Planck constant. The count of the atoms in the spheres will give the sphere mass.

Monitoring the international prototype

Enabled the monitoring of the stability of the international prototype kilogram, which is thought to drift by about 50 µg every 100 years. The prototype drift can be measured, or excluded, by mass comparisons between the prototype and an Si sphere.



A Pt-Ir kilogram reflected next to the Si-28 sphere.

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EMRP
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