Using the Avogadro Constant as a New Standard for Mass

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Most people who have studied chemistry will probably remember an eccentric portrait of Italian physicist Amedeo Avogadro (1776—1856) that crops up in many textbooks. Avogadro hypothesized that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules. This principle, now known as Avogadro's law, is today one of the most fundamental laws for physics and chemistry.

Improving the Accuracy of the Avogadro Constant

How many molecules are contained in 1 mole of gas? Avogradro does not offer a specific number for this quantity. At the time, no proof of the existence of atoms and molecules existed, and the theory on which these entities are based had not yet been validated experimentally. Today the internationally accepted value for the Avogadro constant is 6.022 1415 $\times 10^{23}$ mol^{-1} (recommended in 2002 by the Committee on Data for Science and Technology (CODATA)). The constant is defined as the number of atoms or molecules in a single mole, which in turn is defined as 0.012 kg of ^{12}C. Since the beginning of the 20th century, numerous researchers have engaged in an interminable series of tests and measurements, striving to find an accurate value for the Avogadro constant. Since the 1920s, when X-ray diffraction was deployed for the first time, the accuracy of these measurements has steadily increased. The most startling progress of all has come the past decade, thanks to the emergence of the X-ray crystal density method and growth technologies for silicon crystals.

Because the Avogadro constant is such a fundamental constant in physics and chemistry, the discovery of more accurate values for this number is of monumental importance for basic chemistry. The implications are likely to be felt not just in laboratories, but in broad areas of everyday life as well, because of one radical outcome: the redefinition of the basic unit of mass, the kilogram.

Redefining the Kilogram

Of all the weights and measures that form the basis of the International System of Units, only the kilogram, the unit of mass, continues to be based on a material artifact. As discussed above, all of the other base units have already been redefined using physical principles. For example, the unit of time, the second, is based on the radiation period of the cesium atom; the meter, the basis of length, is defined in terms of the distance light travels in a vacuum within a defined period of time.

In its premises in the suburbs of Paris, the International Bureau of Weights and Measures (BIPM) houses the artifact that serves as the standard for the kilogram. Each country signatory to the Metre Convention holds a copy of this artifact. Every 30 years or so, these copies are shipped to Paris for recalibration. Meanwhile, the mass of the artifact itself fluctuates over time, rising as ambient gases are adsorbed on its surface and shrinking whenever it is cleaned. Naturally, these fluctuations compromise the stability upon which the present definition depends. The international community has therefore reached an agreement in principle to redefine the kilogram according to a defined number of atoms, using as accurate a value for the Avogadro constant as possible.

Toward an Atomic Mass Standard

The National Metrology Institute of Japan (NMIJ) is striving to find the most accurate value for the Avogadro constant, using a silicon single-crystal sphere precisely ground to 1 kg. First, the diameter of the high-purity silicon sphere is measured using laser interferometry to obtain a highly precise measure of volume. The density of the sphere is then measured in vacuum, and its lattice constant (the gap between the atoms) and molar mass (average atomic weight based on the three stable isotopes of silicon existing in nature) are determined.

Drawing on these data, in 2002 NMIJ succeeded in determining the Avogadro constant with an uncertainty of 10^{-7} level. This breakthrough contributed significantly to finding the most reliable value for the Avogadro constant as listed above. Based on our value as one of the fundamental input data, CODATA has conducted a comprehensive revision of no fewer than 200 fundamental physical constants.

Future efforts are intended to further reduce isotopic impurities and improve the measurement accuracy to a few parts in 10^8, thereby realizing a new standard for mass based on the Avogadro constant. Through joint research on the international level, the current definition of the kilogram should be obsolete within 10 to 20 years, ushering in a much more readily verifiable and universally reproducible standard for mass.

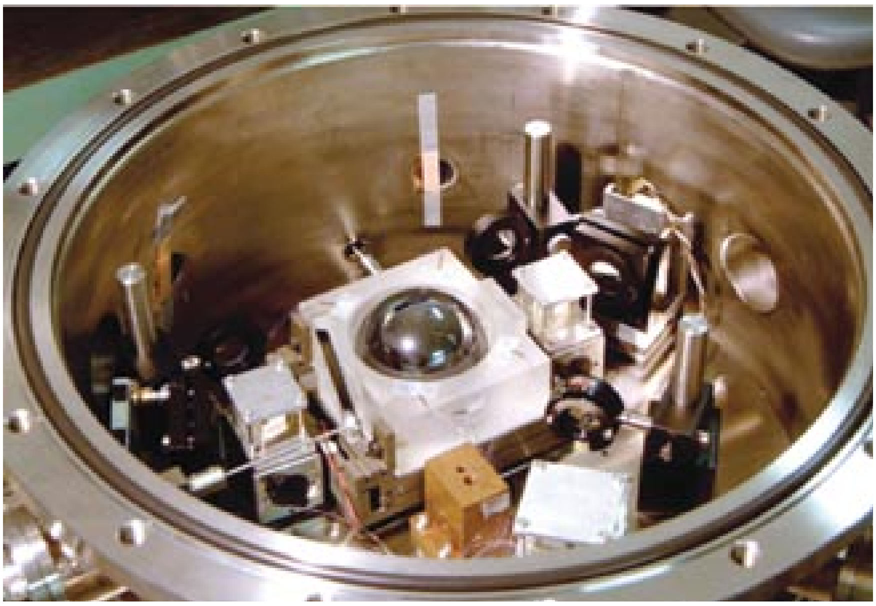

Photo Using laser interferometry to measure the diameter of the silicon sphere