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Insights

Redefining The Kilogram

A new kilogram standard is coming. What does it mean for science?

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SCIENTISTS HAVE SPENT the better part of the past four centuries, since the early days of the Enlightenment, discovering the truth about how the natural world works. A critical part of this endeavor is determining the physical constants of the universe and establishing standards for measuring them. Exactly how this process shakes out is fascinating to observe, even if the details are sometimes painful to endure.

Take the kilogram, for example. The kilogram (mass) is one of the seven base units of the International System of Units (SI). The others are the meter (length), second (time), ampere (electric current), kelvin (temperature), mole (amount of substance), and candela (light intensity).

BIPM

The international kilogram prototype. The kilogram is the last of the SI base units that is still defined by a physical artifact.

The kilogram is the last of the SI base units that is still defined by a physical artifact rather than by an unvarying physical property of nature. It's currently equal to the mass of a golf-ball-sized cylinder of platinum-iridium alloy. This surprisingly small lump of metal, known as the international prototype, was ratified as the official kilogram in 1889. The prototype is kept in a vault, along with six copies, at the International Bureau of Weights & Measures (BIPM) near Paris.

Altogether, 90 calibrated platinum-iridium copies of the international prototype exist throughout the world. The official U.S. kilogram, K20, is secured in a vault at the National Institute of Standards & Technology headquarters in Gaithersburg, Md. NIST maintains a number of stainless steel working copies of K20 by which balances, weight sets, and anything to do with weighing can be validated by NIST technicians for a fee.

The international prototype is not immutable, however. It has inexplicably lost about 50 µg over time compared with its copies. Some scientists have rightly pointed out that it's not good for an SI base unit like the kilogram to drift because the imprecision propagates uncertainty in other SI units that are based on the kilogram. A BIPM committee therefore recommended in 2005 that the kilogram be redefined in terms of an unvarying property of nature.

This new standard could be derived by assigning an exact value to Planck's constant or to Avogadro's constant. Planck's constant (h), which describes the quantization of energy in matter, is related to mass (m) by $hĐ = mc^2$, where Đ is frequency and c is the speed of light. Fixing h at the proposed value of $6.6260693 \times 10^{-34}$ joule-seconds would remove the uncertainty associated with its experimental measurement and fix the definition of the kilogram.

As for Avogadro's constant, it is currently defined as exactly the number of atoms in 12 g (one mole) of ^{12}C, which is a measurable value reported with an experimental uncertainty. By assigning an exact value to Avogadro's constant, which could be done by rounding the current measured value to a number that is divisible by 12, it would become exactly 6.0221418×10^{23}, and the kilogram would be equal to the mass of 5.0184515×10^{25} ^{12}C atoms.

The latter proposal is more palatable to chemists because it conveniently ties the kilogram to the mole and Avogadro's constant, which are two measures at the heart of chemistry. But the BIPM committee making the decision, which is expected in 2011, takes the physics view that using Planck's constant will more comprehensively tie in quantum mechanics to the SI base units.

With either proposal, the international prototype could be calibrated according to the new definition and retained as the prototype. So in effect, the kilogram will still be the same kilogram when the redefinition process is all said and done. That realization takes a little of the sparkle out of the process for spectators.

THERE'S A LITTLE BIT more to the story though. Even if the Avogadro's constant proposal loses out, Avogadro's constant might still be redefined as Avogadro's number. Avogadro's constant is the "number of entities" in a mole of any material and has the unit mol^{-1}. The potential change would decouple it from the current definition based on the abstract idea of a number of entities and make it a pure counting number, like a dozen, with no unit. That's the way Avogadro's number was originally defined before it officially became a constant in 1971. With the change, the value of Avogadro's number wouldn't be any different from Avogadro's constant, although it would be experimentally derived from Planck's constant via the kilogram.

That outcome would still be a small victory for chemists, according to Paul J. Karol, a chemistry professor at Carnegie Mellon University and chair of the American Chemical Society's Committee on Nomenclature, Terminology & Symbols. Karol has been involved in the kilogram debate and helped formulate the Avogadro's constant proposal (C&EN, March 17, page 48).

From an educator's point of view, the change would make understanding Avogadro's number and the mole a little easier for students, Karol says. Aside from that, the only other impact is that some chemistry textbooks might need minor revision if they don't already use Avogadro's number.

All this kibitzing about the kilogram turns out to be meaningful only to an extremely small set of practitioners: namely metrologists, who are involved in the science of measurements. But the process provides a snapshot of the minutiae that scientists must sometimes worry about and some insight into how scientists try to resolve sticky issues in a rational fashion.

Views expressed on this page are those of the author and not necessarily those of ACS.

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