Defining a New Kilogram

The *second* is defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom. *One meter* is defined as the length of the path traveled by light in vacuum during a time interval of 1/299,792,458 of a second. *One kilogram* is the unit of mass that is equal to a 118-year old platinum and iridium cylinder that is stored just outside Paris.

If you don't think that last measure quite matches the others, you're not alone. Oh, and by the way, during the past 118 years, that cylinder, called Le Gran K, has lost about 50 μg of mass.

That's why two Georgia Institute of Technology (Georgia Tech; Atlanta) professors have proposed redefining the kilogram as a certain number of carbon-12 atoms. The current proposed number is $84{,}446{,}886^3$ carbon-12 atoms per gram.

Even though Ronald F. Fox, Regents' Professor Emeritus in the Georgia Tech School of Physics, and Theodore P. Hill, professor emeritus in the School of Mathematics, weren't really looking to redefine the kilogram, they believe they've created a simple and elegant definition. Hill said defining a kilogram as a certain number of atoms is clean, permanent, easy to understand by students, and experimentally neutral.

The idea developed as the pair tried to determine the precise value of Avogadro's number, the number of atoms per mole of an element. The International System of Units (SI) defines the *mole* as "the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12."

"If you were able to precisely set Avogadro's number, then according to the structure of the carbon-12 mass standard, you have automatically predetermined the kilogram," Fox said.

Avogadro's number is typically thought of as 6.023×10^{23} atoms per mole. However, because that value is experimentally determined, the true value of Avogadro's number is a range. But conceptually, to be a unit of quantity, it must be an integer, Hill said.

"What we noticed was that if you thought of Avogadro's number as referring to a physical object that was three-dimensional, you could imagine a cube, and then you could ask how many atoms would have to be on the edge of this cube to correspond to Avogadro's number," Fox said. Since 6.023×10^{23} is about 10^{24} atoms, the edge of the cube would require about 10^8 atoms, and that means you'd need 8 digits of accuracy, he explained.

"It turns out that taking the cubed root of Avogadro's number on the basis of the measured, or empirical, values almost uniquely determines those eight digits," Fox said.

It is a short journey from defining Avogadro's number to defining the kilogram. "Because the atomic mass standard is defined in terms of carbon-12, and 12 grams is exactly Avogadro's number of carbon-12 atoms, it obviously implies a standard for the kilogram," Fox said.

However, since Fox and Hall proposed their number, the National Institute of Standards and Technology has combined its experimental data with data from other labs around the world to refine its opinion of the possible range for Avogadro's number, Fox said. The new range is incompatible with the $84{,}446{,}886^3$ number.

However, the experiments' findings that were combined to calculate the new range for Avogadro's number came from different test methods, and the values differed from one another by more than their respective standard deviations, Fox said.

"We're in limbo at the present time...we can't precisely give our Avogadro's number until we know for sure what the best measured estimate number is going to be," Fox said. "And that seems to be in a state of flux and debate right now."

Why Change?

As detection limits drop into the nanogram range, any change in the accepted value of a kilogram would make measurements variable. For perspective, the 50 μg that Le Gran K has lost is five orders of magnitude greater than the 0.2-ng/L method detection limit listed in U.S. Environmental Protection Agency Method 1631E for the analysis of mercury in water.

"As far as Avogadro's number goes, I'd characterize [50 μg] as huge," Hill said. "It's 150 quadrillion atoms. ... It's an absolutely huge number that we can't even imagine."

"Physicists and chemists alike would like to eliminate artifactual standards such as the kilogram," Fox said. "Everybody would like to eliminate it; the only question is how do you choose to do that?"

Hill said that on a practical level in the average laboratory, this redefinition would be invisible. "This definition is completely consistent with all known values of all the constants," he said.

The practical application of this redefinition, Fox said, would enable users to choose whichever technique they wanted to produce a physical standard against which to make measurements.

In 1999, the 21st General Conference for Weights and Measures, the group that decides how and when to redefine standards, recommended that efforts continue to refine experiments linking mass to fundamental constants with a view to a future "quantum-based" redefinition of the kilogram. Whether this has been achieved will be discussed next at the 24th General Conference in 2011.

— ***Steve Spicer**, Solutions*