A Better Definition for the Kilogram? Scientists Propose a Precise Integer Number of Carbon Atoms

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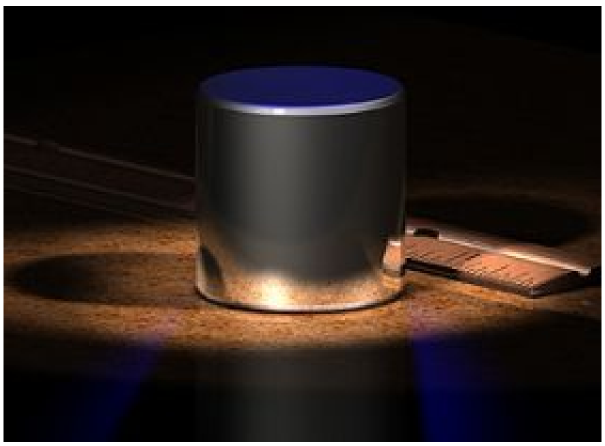

A computer-generated image of the International Prototype Kilogram, which is made from an alloy of platinum and iridium. Image: Wikimedia Commons

How much is a kilogram? It turns out that nobody can say for sure, at least not in a way that won't change ever so slightly over time. The official kilogram – a cylinder cast 118 years ago from platinum and iridium and known as the International Prototype Kilogram or "Le Gran K" – has been losing mass, about 50 micrograms at last check. The change is occurring despite careful storage at a facility near Paris.

That's not so good for a standard the world depends on to define mass.

Now, two U.S. professors – a physicist and mathematician – say it's time to define the kilogram in a new and more elegant way that will be the same today, tomorrow and 118 years from now. They've launched a campaign aimed at redefining the kilogram as the mass of a very large – but precisely-specified – number of carbon-12 atoms.

"Our standard would eliminate the need for a physical artifact to define what a kilogram is," said Ronald F. Fox, a Regents' Professor Emeritus in the School of Physics at the Georgia Institute of Technology. "We want something that is logically very simple to understand."

Their proposal is that the gram – 1/1000th of a kilogram – would henceforth be defined as the mass of exactly 18 x 14074481 (cubed) carbon-12 atoms.

The proposal, made by Fox and Theodore P. Hill – a Professor Emeritus in the Georgia Tech School of Mathematics – first assigns a specific value to Avogadro's constant. Proposed in the 1800s by Italian scientist Amedeo Avogadro, the constant represents the number of atoms or molecules in one mole of a pure material – for instance, the number of carbon-12 atoms in 12 grams of the element. However, Avogadro's constant isn't a specific number; it's a range of values that can be determined experimentally, but not with enough precision to be a single number.

Spurred by Hill's half-serious question about whether Avogadro's constant was an even or odd number, in the fall of 2006 Fox and Hill submitted a paper to Physics Archives in which they proposed assigning a specific number to the constant – one of about 10 possible values within the experimental range. The authors pointed out that a precise Avogadro's constant could also precisely redefine the measure of mass, the kilogram.

Their proposal drew attention from the editors of American Scientist, who asked for a longer article published in March 2007. The proposal has so far drawn five letters, including one from Paul J. Karol, chair of the Committee on Nomenclature, Terminology and Symbols of the American Chemical Society. Karol added his endorsement to the proposal and suggested making the number divisible by 12 – which Fox and Hill did in an addendum by changing their number's final digit from 8 to 6. So the new proposal for Avogadro's constant became 84446886 (cubed), still within the range of accepted values.

Fast-forward to September 2007, when Fox read an Associated Press article on the CNN.com Web site about the mass disappearing from the International Prototype Kilogram. While the AP said the missing mass amounted to no more than "the weight of a fingerprint," Fox argues that the amount could be significant in a world that is measuring time in ultra-sub-nanoseconds and length in ultra-sub-nanometers.

So Fox and Hill fired off another article to Physics Archive, this one proposing to redefine the gram as 1/12th the mass of a mole of carbon 12 – a mole long being defined as Avogrado's number of atoms. They now hope to generate more interest in their idea for what may turn out to be a competition of standards proposals leading up to a 2011 meeting of the International Committee for Weights and Measures.

At least two other proposals for redefining the kilogram are under discussion. They include replacing the platinum-iridium cylinder with a sphere of pure silicon atoms, and using a device known as the "watt balance" to define the kilogram using electromagnetic energy. Both would offer an improvement over the existing standard – but not be as simple as what Fox and Hill have proposed, nor be exact, they say.

"Using a perfect numerical cube to define these constants yields the same level of significance – eight or nine digits – as in those integers that define the second and the speed of light," Hill said. "A purely mathematical definition of the kilogram is experimentally neutral – researchers may then use any laboratory method they want to approximate exact masses."

The kilogram is the last major standard defined by a physical artifact rather than a fundamental physical property. In 1983, for instance, the distance represented by a meter was redefined by how far light travels in 1/299,792,458 seconds – replacing a metal stick with two marks on it.

"We suspect that there will be some public debate about this issue," Fox said. "We want scientists and science teachers and others to think about this problem because we think they can have an impact. Public discussion may play an important role in determining how one of the world's basic physical constants is defined."

How important is this issue to the world's future technological development?

"When you make physical and chemical measurements, it's important to have as high a precision as possible, and these standards really define the limits of precision," Fox said. "The lack of an accurate standard leaves some inconsistency in how you state results. Having a unique standard could eliminate that."

While the new definition would do away with the need for a physical representation of mass, Fox says people who want a physical artifact could still have one – though carbon can't actually form a perfect cube with the right number of atoms. And building one might take some time.

"You could imagine having a lump of matter that actually had exactly the right number of atoms in it," Fox noted. "If you could build it by some kind of self-assembly process – as opposed to building it atom-by-atom, which would take a few billion years – you could have new kilogram artifact made of carbon. But there's really no need for that. Even if you built a perfect kilogram, it would immediately be inaccurate as soon as a single atom was sloughed off or absorbed."

Source: Georgia Institute of Technology

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