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The Kilogram Cabal

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A large, expensive device, like this one at the National Institute of Standards and Technology, is needed to gauge the Planck kilogram, the proposed new standard measure of mass.

By Theodore P. Hill | JULY 02, 2012

The International Committee for Weights and Measures is about to reach a decision that could affect the teaching and understanding of basic science for the next hundred years. It has passed a resolution proposing a radically new definition for a ubiquitous word: "kilogram."

Is a new official definition of the kilogram necessary? The rule of thumb—that a kilogram is about the mass of one liter of water—works perfectly well for everyday use. When we read that our granola bar contains six grams of saturated fat, or that police seized 10 kilograms of cocaine, we understand. That informal definition of the kilogram, however, is not precise enough for state-of-the-art scientific purposes.

The official international system of units of measurement is based on seven independent base quantities: time, length, mass, electric current, temperature, luminous intensity, and amount of substance. In response to ever-increasing demands for accuracy, the definitions of the units for measurement of those quantities have evolved over time.

For example, the base unit to measure time, the second, was once defined in terms of the average period of the earth's orbit around the sun. Today it is defined in atomic terms, as the duration of a specified number of transitions of a cesium-133 atom. The base unit of length, the meter, was once defined to be one 10-millionth of the distance between the equator and the North Pole along a meridian passing through Paris. The current official definition of a meter is the length of the path traveled by light in a vacuum during a specified fraction of a second.

The unit to measure mass, however, is a different kettle of fish. The kilogram is the only one of the seven base units still defined in terms of a physical artifact. The scientific definition of a kilogram in 2012 is one that has been used since 1889. One kilogram is the mass of a certain 19th-century platinum-iridium cylinder, affectionately known as Le Grand K, which is stored under guard in a sealed vault near Paris. More precisely, the official definition of a kilogram is the mass of that object shortly after it is cleaned in a prescribed manner.

As intriguing as that definition is, it does not meet the needs of modern science. Physicists are now able to pick up and move a single atom. The required cleaning of Le Grand K removes trillions of atoms of platinum and iridium, and deposits trillions of atoms from the solvents and gloves used in the cleaning. Thus the mass of Le Grand K is changing measurably in time, and, consequently, the mass of every atom in the universe (measured in the official unit) is changing along with it.

Experts across scientific disciplines agree that we need a new definition of the kilogram, one based on a constant of nature. Experts also agree that the new definition should be accessible to anyone, anywhere, anytime, and should be comprehensible to students in all disciplines. We should be able to share the beautiful ideas of science with our friends and colleagues in history and English, with a minimum of jargon and technicalities. But that is not the direction in which the process is moving.

In 2005, three researchers from the U.S. National Institute of Standards and Technology and two colleagues from Europe identified two possible redefinitions: an atomic kilogram and a Planck kilogram.

The atomic kilogram invokes the mass of a specified number (about 370 million cubed) of carbon-12 atoms. That is easy to understand and to teach, as it requires knowing only what a carbon-12 atom is. It is also easy to visualize—picture a block of carbon about 370 million atoms (or 8.11 centimeters) on a side.

The Planck proponents, on the other hand, define the kilogram as the mass that would make Planck's constant a specified value (a number 35 digits long). To understand the Planck kilogram, you first need to recall Planck's constant (the relationship between the energy in one quantum of electromagnetic radiation and the frequency of that radiation). Then you must work backward, using an appropriate equation in quantum physics, together with the equation $E = mc^2$ from Einstein's theory of special relativity.

In other words, to understand the Planck kilogram, one needs a good working knowledge of both quantum physics and special relativity. Not only is that challenging for most of us, but this definition of a kilogram is almost impossible to visualize.

Only a year after identifying those two potential redefinitions of the kilogram, the same team of five scientists recommended the Planck kilogram. Shortly thereafter, the Committee for Weights and Measures voted to adopt it.

Many scientists wonder why.

Last year Jack Miller, a physicist at the Lawrence Berkeley National Laboratory; Albert C. Censullo, a chemist at California Polytechnic State University; and I, a Georgia Tech mathematician, compared the relative merits of the atomic and Planck kilograms in a paper, "Toward a Better Definition of the Kilogram." We found the atomic kilogram definition to be superior.

The atomic kilogram is much easier to comprehend and to teach. You can build a simple, rough prototype of a kilogram mass in a college laboratory, or even in a kitchen sink: Simply cut a block of nearly pure carbon so that it is roughly 8.11 centimeters on a side—that's approximately one kilogram. Visualizing a Planck kilogram is not so easy. To measure Planck's constant, you need an electromechanical device called a watt balance. The watt balance at the National Institute of Standards and Technology is two stories high and requires a team of three to five experts, as well as the considerable use of expensive liquid helium for two superconducting magnets. There is no simple way to construct a rough Planck kilogram even in state-of-the-art university laboratories, let alone in a classroom.

The Russian metrologist V.V. Khruschov performed an independent comparison of the atomic and Planck kilograms and also concluded that the atomic kilogram was superior. He lamented that the basis of the Planck definition rested not on a natural invariant, such as the mass of a carbon atom, but rather on the watt balance—a "complicated electromechanical device with many sources of systematical uncertainties."

Each definition has its own advantages, of course, but even the designers of the Planck kilogram agreed that the atomic kilogram is easier to understand. So why is the Planck kilogram definition holding sway?

One reason is simple: the personal preferences of the powers that be. The president of the Committee on Units of the Committee for Weights and Measures—which voted to adopt the Planck kilogram—is the lead author of those same five researchers who dreamed it up in the first place. As he explained to me by e-mail, "Quantum physics ... has been the fascination of my life. ... I love it."

How many others of the Committee on Units share his passion for quantum physics? It's hard to say, since the group meets behind closed doors. Chemists are keenly interested in the precise definition of the kilogram, and representatives of the American Chemical Society recently asked permission to observe the proceedings of the Committee on Units. Their request was denied on the basis of the panel's Rule C: The Committee on Units has no observers.

The Georgia Tech physicist Ronald F. Fox and I e-mailed the five architects of the Planck kilogram, asking what their proposed textbook definition of the kilogram would be. One of them, from the National Institute of Standards and Technology, responded by e-mail: "I am not in the business of writing introductory textbooks—I will leave that to others." Our repeated requests over the past five years for an introductory-textbook definition of the Planck kilogram have been fruitless.

When we explained how difficult the Planck kilogram would be to grasp, even for physics majors, the president of the Committee on Units (one of the inventors of the Planck kilogram, remember) argued that the members of the younger generation are savvier than we give them credit for. "Of course they are not right up there with quantum mechanics," he wrote, "but it is not completely unfamiliar to them." In short, if you don't understand the Planck kilogram, you are either stupid or behind the scientific times.

Another reason for the choice of the Planck kilogram, of course, is money. Public resources for science are limited, and too often it is the funding tail that wags the science dog. The National Institute of Standards and Technology is one of the three or four laboratories in the world that has invested millions of dollars in watt-balance equipment and the personnel to experimentally determine the Planck constant. So it should come as no surprise that an institute-heavy team rejected the elegant and easily understood atomic kilogram.

Advocates of the Planck kilogram defended their choice, writing that "teachers or students ... have said very little" about the proposal. My guess is that most physics and chemistry professors are simply unaware of this important debate.

But now is your chance. The kilogram conundrum presents a unique opportunity for science professors and teachers to actively participate in determining the scientific legacy we leave to the next generation.

It is not too late to tell the Committee on Weights and Measures and the National Institute of Standards and Technology which definition you prefer. Without such participation, the Planck kilogram will win by default, and that, in my opinion, will drive yet another wedge between science and society at large. If the Planck kilogram becomes official, I would not want to be in professors' shoes when some wiseacre in the class pipes up, "What exactly is a kilogram, anyway?" That will surely happen, as we well know, for we were once wiseacres ourselves.

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