Scientists Struggling to Make the Kilogram Right Again

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Correction Appended

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Photo: Dr. Arnold Nicolaus cleans a silicon ball, which scientists are looking at as a new definition of the kilogram. (Otto Pohl for The New York Times

BRAUNSCHWEIG, Germany— In these girth-conscious times, even weight itself has weight issues. The kilogram is getting lighter, scientists say, sowing potential confusion over a range of scientific endeavor.

The kilogram is defined by a platinum-iridium cylinder, cast in England in 1889. No one knows why it is shedding weight, at least in comparison with other reference weights, but the change has spurred an international search for a more stable definition.

"It's certainly not helpful to have a standard that keeps changing," says Peter Becker, a scientist at the Federal Standards Laboratory here, an institution of 1,500 scientists dedicated entirely to improving the ability to measure things precisely.

Even the apparent change of 50 micrograms in the kilogram -- less than the weight of a grain of salt -- is enough to distort careful scientific calculations.

Dr. Becker is leading a team of international researchers seeking to redefine the kilogram as a number of atoms of a selected element. Other scientists, including researchers at the National Institute of Standards and Technology in Washington, are developing a competing technology to define the kilogram using a complex mechanism known as the watt balance.

The final recommendation will be made by the International Committee on Weights and Measures, a body created by international treaty in 1875. The agency guards the international reference kilogram and keeps it in a heavily guarded safe in a château outside Paris. It is visited once a year, under heavy security, by the only three people to have keys to the safe. The weight change has been noted on the occasions it has been removed for measurement.

"It's part ceremony and part obligation," Dr. Richard Davis, head of the mass section at the research arm of the international committee.

"You'd have to amend the treaty if you didn't do it this way."

That ceremony has become a little sorrowful as the guest of honor appears to be, on a microscopic level at least, wasting away.

The race is already well under way to determine a new standard, although at a measured pace, since creating reliable measurements is such painstaking work.

The kilogram is the only one of the seven base units of measurement that still retain its 19th-century definition. Over the years, scientists have redefined units like the meter (first based on the earth's circumference) and the second (conceived as a fraction of a day). The meter is now the distance light travels in one-299,792,458th of a second, and a second is the time it takes for a cesium atom to vibrate 9,192,631,770 times. Each can be measured with remarkable precision, and, equally important, can be reproduced anywhere.

The kilogram was conceived to be the mass of a liter of water, but accurately measuring a liter of water proved to be very difficult. Instead, an English goldsmith was hired to make a platinum-iridium cylinder that would be used to define the kilogram.

One reason the kilogram has lagged behind the other units is that there has been no immediate practical benefit to increasing its precision. Nonetheless, the drift in the kilogram's weight carries over to other measurements. The volt, for example, is defined in terms of the kilogram, so a stable kilogram definition will allow the volt to be tied more closely to the base units of measure.

A total of 80 copies of the reference kilogram have been created and distributed to signatories of the metric treaty. The sometimes colorful history of these small metal cylinders underscores how long the world has used the same definition of the kilogram.

Some of the metal plugs were issued to countries that later vanished, including Serbia and the Dutch East Indies. The Japanese had to surrender theirs after World War II. Germany has acquired several weights, including the one issued to Bavaria in 1889 and the one that belonged to East Germany.

To update the kilogram, Germany is working with scientists from countries including Australia, Italy and Japan to produce a perfectly round one-kilogram silicon crystal. The idea is that by knowing exactly what atoms are in the crystal, how far apart they are and the size of the ball, the number of atoms in the ball can be calculated. That number then becomes the definition of a kilogram.

To separate the three isotopes of silicon, Dr. Becker and his team are turning to old nuclear weapons factories from the Soviet Union, where centrifuges once used to produce highly enriched uranium are able to produce the required purity of silicon.

"We need so many nines," Dr. Becker said, and Soviet uranium processors are one of the only places to get them. "With the Russians, we're getting about four of them," or 99.99 percent pure silicon 28.

A test crystal has already been produced, and Dr. Arnold Nicolaus, another scientist at the German standards laboratory, is responsible for measuring whether it is perfectly round. He has measured the crystal in a half-million places to determine its shape.

It's probably the roundest item ever made by hand. "If the earth were this round, Mount Everest would be four meters tall," Dr. Nicolaus said. An intriguing characteristic of this smooth ball is that there is no way to tell whether it is spinning or at rest. Only if a grain of dust lands on the surface is there something for the eye to track.

Scientists from the United States, England, France and Switzerland say the challenge of calculating the precise number of atoms in a silicon crystal is too imprecise with today's technology so they are refining a technique to calculate the kilogram using voltage.

"Measuring energy is easier than counting atoms," said Dr. Richard Steiner, a scientist at the National Institute of Standards and Technology in Washington, who is leading the international project to create the watt scale.

In the last few weeks, he has reported that his experiments have yielded data that are close to what they need. "Now we're into the picayune, itsy-bitsy errors," he said, having recently corrected "totally ridiculous" errors of 100 parts per million.

The idea of the watt balance is to measure the electromagnetic force needed to balance a reference kilogram. As long as the gravitational field is precisely known for the location of the experiment, the mass on the scale can be related to power. (The gravitational field is a complicated calculation that needs among other things constantly updated changes in tidal forces.)

The definition of the kilogram would then be a measurement of that power or in terms of something that could be derived from it, like the mass of an electron. The experiment in Washington is occurring in a large three-story structure, but in spite of the complexity and circuitous route of calculating mass, Dr. Steiner says he is confident that his team will have persuasive data shortly.

"In the short term, I think we'll win," he said.

Dr. Davis, who is working closely with those making the final decision about the fate of the kilogram, says he is not so sure. "In terms of published results, the watt balance is closer of the two," he said. "But it's very hard to say which is better."

Many scientists believe that the most elegant way to define the kilogram is by counting out a kilo's worth of atoms of an element. A project is under way to test that with gold atoms. But the sheer number of atoms in a kilogram, a number with roughly 25 digits in it, makes that approach unfeasible for the foreseeable future.

For now, Dr. Davis is willing to set his sights lower in the error-prone world of superprecision measurements. "It would be nice," he said, "just to have two experiments in the world that agreed with each other."

Correction Appended
For mysterious reasons, a platinum-iridium cylinder that defines the kilogram has been losing weight. So scientists are looking for other ways to set the standard. COUNTING ATOMS OF A SILICON CRYSTAL A crystal sphere that weighs exactly one kilogram is created. Since its atomic structure is known, by measuring the spheres diameter one can calculate how many atoms it contains. That number would define kilogram. WATT BALANCE A one kilogram mass connected to a movable coil that would be suspended within the field of a fixed magnet. The coil can be driven up by electromagnetic force when electrical current is applied to it. The upward force can be adjusted to just balance the weight of the one kilogram mass. When in balance, the electrical current can be measured, and the necessary electrical power calculated. That, in turn, could be used to define the kilogram. (Sources: Dr. Richard Steiner, N.I.S.T.; Dr. Peter Becker, Federal Standards Laboratory, Braunschweig, Germany)