Revamping the measure of mass: new efforts bring scientists closer to redefining kilogram

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The metric system is on track for a mass makeover.

In an effort to provide accurate measurements at all scales, scientists are preparing to redefine four basic units by the end of 2018. The shift will most notably affect the kilogram, the base measure of mass and the last member of the International System of Units still defined by a physical object. Efforts are under way to check and fine-tune measurements of fundamental natural quantities--including Avogadro's number--that scientists will use to give the kilogram a new mathematical definition.

Since 1889, the standard for mass has been a 1-kilogram cylinder of platinum and iridium metal kept at the Bureau International des Poids et Mesures in Sevres, France. While this standard is handled carefully, it's at risk of becoming dirty or damaged, says Michael Stock, a physicist at the bureau. "Any material object can change over time."

It's also difficult to accurately scale this physical standard down to very small masses, like those of electrons, says physicist David Newell of the National Institute of Standards and Technology in Gaithersburg, Md.

Scientists aim to give the kilogram a new definition based on nature's fundamental physical constants. This task requires a highly accurate measurement of Planck's constant, which links energy and frequency. Scientists can use Planck's constant to measure and describe mass, as the two are mathematically connected through another natural constant, the speed of light. Researchers are using the existing physical definition of a kilogram to measure Planck's constant as accurately as possible. Then this value can be set in stone and used to define mass in the future.

One way to do this is with devices called watt balances. Scientists measure Planck's constant using precisely known standards, including those for mass and electrical current. Once Planck's constant has been fixed, watt balances then use the constant to calculate unknown mass.

In another approach, scientists count the number of atoms in extremely pure 1-kilogram silicon spheres. This number allows scientists to calculate a different fundamental value, the Avogadro constant (or Avogadro's number). This constant describes the number--roughly 6.02 x 1023--of units per mole, the metric unit for an amount of a substance. (A mole is the mass of a substance equal to its atomic or molecular weight expressed in grams.) A precise Avogadro constant can be used to calculate and confirm Planck's constant.

After cleaning, repolishing and remeasuring silicon orbs used for previous measurements, a team of researchers reported a new value of the Avogadro constant in Metrologia in March. When the new value and its uncertainty are averaged with previous calculations, the Avogadro constant comes out to 6.02214082 x [10.sup.23] with an uncertainty of 18 parts in a billion, scientists report in the September

Journal of Physical and Chemical Reference Data. This number is slightly smaller than the value of the constant currently described by NIST--6.022140857 x [10.sup.23].

The watt balance and atom-counting techniques now give nearly identical values of Planck's constant, with an uncertainty of less than 20 parts in a billion, says metrologist Ian Robinson of the National Physical Laboratory in Teddington, England. Scientists are still working to generate additional measurements and even lower uncertainties.

[ILLUSTRATION OMITTED]

In 2018, international delegates at a meeting of the General Conference on Weights and Measures will decide whether to approve the kilogram's new definition. Based on existing plans, many believe the redefinition will happen at this time, Stock says.

Because researchers' careful calculations have accounted for the existing definition of mass, the redefinition should cause no perceptible shift in measurement. "If we do our jobs right, nobody's going to notice a thing," says Newell. But future mass measurements should become stable, Robinson says.

While redefining the kilogram will be the most critical change ahead, Stock says, scientists also hope to redefine other units, including the mole and the kelvin, which measures temperature. These redefinitions will depend on fixing other constants, including the Avogadro constant. Making all of these changes at once will limit the number of times textbooks must be changed, Stock says.

The redefinitions won't mark an end to the quest for a perfect metric system, Newell says. "Metrologists are going to make the measurement exactly right. And the corollary is, they never finish their measurement."

[ILLUSTRATION OMITTED]

Caption: This metal cylinder is a copy of the international kilogram kept in France. Scientists want to replace this standard, the last physical object used to define a unit of the metric system.

Caption: Newly calculated value of the Avogadro constant

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