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RESEARCH NEWS

Nailing Down Four Fundamental Constants

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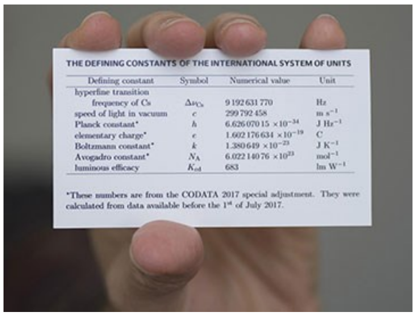

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A NIST wallet card displays the fundamental constants and physical values that will define the revised system of SI units. [Image: Stoughton/NIST] [Enlarge image] (/opn/media/Images/Homepage/Newsroom/1117/News-06Nov-Icon-large.jpg)

An international task force of metrologists has updated the values of four fundamental constants—Planck's constant (*h*), the elementary charge (*e*), Boltzmann's constant (*k*); and Avagadro's number, N_A (Metrologia, doi: 10.1088/1681-7575/aa950a (https://doi.org/10.1088/1681-7575/aa950a)).

The new values for these constants, which rest on an analysis of state-of-the-art measurements from a worldwide assemblage of metrology labs, won't, alas, change the morning reading on your bathroom scale. But they're a big deal for metrologists, as they set up a comprehensive reassessment of the International System of Units (SI), or metric system, slated for November 2018—when the metrology community is expected to redefine all seven basic SI units solely in terms of fundamental constants and invariant properties of atoms.

Moving away from physical artifacts

The redefinition of these fundamental constants represents the latest step in a long, slow march away from physical, "artifact-based" SI standards and toward standards based on exact values of fundamental constant. Perhaps the most celebrated physical standard was the platinum-iridium bar located in Paris that, for decades, denoted the precise dimensions of the basic SI unit of length, the meter.

After a long process—during which the scientific community tried, and failed, to replace the bar with a universally accepted standard based a wavelength of light—the metrology community eventually simply turned the problem around. Metrologists defined a fundamental constant, the speed of light in vacuum (*c*), as an exact value (299,792,458 m/s) and used that fundamental constant to define the exact length of a meter. (For more on the standard-meter story, see "Mercury-198 and the Standard Meter," (http://www.osa-opn.org/home/articles/volume_28/september_2017/features/mercury-198_and_the_standard_meter/) OPN, September 2017.)

Dethroning "Le Grand K"

Metrologists would like to achieve a similar fundamental-constant-based standard for all seven basic SI units: the meter, the second, the mole, the ampere, the kelvin, the candela, and the kilogram. This would enable researchers worldwide to make authoritative measurements using precisely the same standard units anywhere on the planet, and on any scale of measurement.

The kilogram constitutes a particular thorn in the metrology community's side; it is the last remaining SI unit that still is defined by a physical artifact—"Le Grand K," a platinum-iridium cylinder stored in France that has represented the standard kilogram since 1879. In principle, that means that local standards for the kilogram elsewhere in the world must be calibrated directly against that physical original.

In other cases, standard SI units have been defined by theoretical ideals difficult to realize in practice. For example, temperature has been defined in terms of the triple point of pure water in a sealed glass cell—begging the question of how to make the water sufficiently pure, and of potential measurement inaccuracies as one gets farther and farther from the triple point.

Hammering down uncertainties

In principle, defining the SI measurements in terms of the exact value of fundamental constants avoids these local and practical difficulties—but it requires a highly precise, international consensus definition of the values of the constants themselves. The work of creating those consensus values for *h*, *e*, *k*, and N_A falls to the Task Group on Fundamental Constants of the international Committee on Data for Science and Technology (CODATA), which periodically reviews fundamental-constant values based on the best available experimental evidence. The team proceeded by collecting measurements from multiple techniques and labs, and using a number of techniques to harmonize the data and minimize uncertainties.

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For the redefinition of Planck's constant and Avogadro's number, for example, the CODATA task group relied on a suite of measurements using a so-called Kibble balance and X-ray crystal-density measurements of a specific sphere of ultrapure silicon-28. As a result, the task group was able to hammer down uncertainties in these constants to just four parts per billion.

Relevant to precise measurements

The four new constant definitions join three other constants—the speed of light, the hyperfine transition frequency of cesium ($\Delta\nu_{Cs}$), and the luminous efficacy constant (K_{cd})—that have previously been exactly defined, and have been used to provide definitions of units such as the meter, the second and the candela. The new definition of Planck's constant, which has units of kg-m^2/s, will be used to provide a worldwide, invariant definition of the kilogram, replacing "Le Grand K"; the new standard Boltzmann's constant will underlie a constant-based definition of the kelvin temperature unit, superseding the definition based on the triple point of water.

The task group members stress that the changes to these constants will have little relevance day to day, in the lab or elsewhere. "The whole thing," said Peter Mohr, a member of the task group who works at the U.S. National Institute of Standards and Technology, "is geared to not have any impact on the average person." Yet it the shift will have considerable relevance to contemporary metrology researchers, whose work increasingly involves measurements at precisions undreamed of in earlier eras.

For this reason, according to CODATA, while the shift to the full suite of SI units based on the new values of these fundamental constants will be decided in November 2018, its official rollout won't come until 20 May 2019—"World Metrology Day"—to give the community time to adapt.

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