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News & Highlights

Redefining the Kilogram

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In November 2018, scientists from 60 countries voted unanimously to redefine the kilogram and three other standard units of measure: the ampere, for electrical current; the kelvin, for temperature; and the mole, which describes the amount of a chemical substance [1].

Up until the vote, the kilogram had been based on a platinum-iridium cylinder called Le Grande K (Fig. 1), which is stored under three glass bell jars at the International Bureau of Weights and Measures (BIPM) in Paris. Starting on 20 May 2019, also known as World Metrology Day, the kilogram will be defined in terms of the Planck constant, a number that relates a radio wave's energy to its frequency. With the new kilogram standard, all seven units in the International System of Units (SI) will no longer be defined by physical objects but will instead be defined in terms of constants of nature.

Attempts to create standardized systems of measurement date back more than 5000 years, based on common concepts such as the length of an arm or the weight of a seed. But such systems were burdened by a lack of consistency across regions. In 1875, inspired by the French Revolution, 17 nations signed the Meter Convention, also known as the Treaty of the Meter, in Paris. The treaty established international standards for the meter and the kilogram, with the latter set equal to the mass of 1 L of water at 4 °C [2]. The goal was to create a system of measurement "for all time, for all people"—an idea attributed to French mathematician and philosopher Marquis de Condorcet.

Scales across the globe, from the ones used by local grocers to those used at international ports, are calibrated with a weight that can trace its own calibration back to Le Grand K—and therein lies the problem. "We know that it's been drifting," said United States National Institute of Standards and Technology (NIST) physicist Darine Haddad, referring to the consensus among metrologists (those who study metrology, the science of measurement) that Le Grand K has mysteriously become lighter than its six official copies by about 50 μg (roughly the weight of an eyelash) [3]. Because mass everywhere is tied to Le Grand K, every time this prototype loses mass, the rest of the universe, by definition, gets heavier.

Owing to the impermanent nature of physical objects, such as Le Grand K, scientists have sought to create more immutable standard units of measurement with definitions built from the basic building blocks of the universe. In 1967, for example, scientists redefined the second as the amount of time it takes an atom of cesium-133 to vibrate 9 192 631 770 times [4]. A resulting benefit of the new standard for time was the development of Global Positioning System (GPS) technology, which requires the keeping of time to one-billionth of a second per day [5]. More precise standards for the kilogram, as well as the ampere, kelvin, and mole, may likewise pave the way for additional technological breakthroughs.

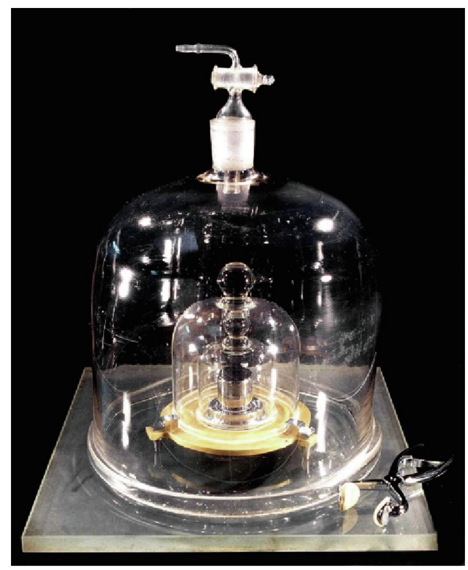

Fig. 1. Since 1889, a squat cylinder of platinum alloy known as Le Grand K has been the global standard for the mass of the kilogram. As it has since it was forged, Le Grand K sits under three glass bell jars in a vault outside Paris. Credit: BIPM.

Over the years, a handful of efforts to redefine the kilogram have stalled out. But in 1975, Bryan Kibble, a physicist at the National Physical Laboratory in London, invented a device (renamed the Kibble balance after his death) that could measure electrical current in terms of weight with extremely high precision (Fig. 2). Around the same time, discoveries in quantum mechanics linking the Planck constant with electrical voltage and resistance made it clear that the Kibble balance could also measure the Planck constant [1].

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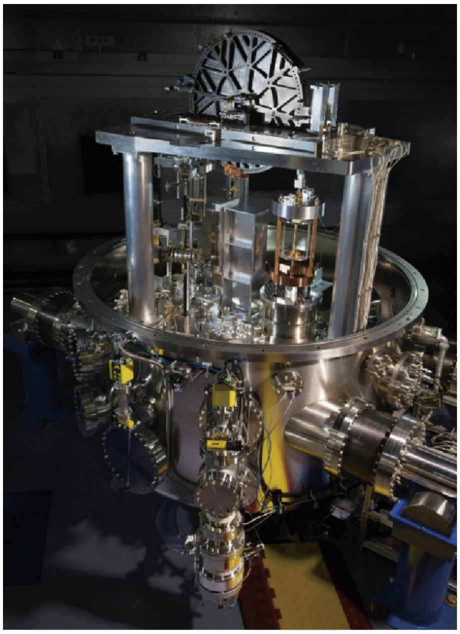

Fig. 2. Kibble balances, such as this one built by NIST physicists, are electromechanical measuring instruments designed to equalize one force with another. In this case, the weight of a test mass is exactly offset by a force produced when an electrical current is run through a coil of wire immersed in a surrounding magnetic field. The extremely high precision of the device provides the basis for the redefinition of the kilogram, set to take effect on 20 May 2019. Credit: J.L. Lee/NIST.

Recently, by weighing an exact copy of Le Grand K with the Kibble balance, physicists derived the Planck constant to within eight decimal places [6]. With the Planck constant set, the kilogram will now correspond to a specific amount of current in the Kibble balance.

Most people will never notice the transition to the new kilogram. For scientists, however, the new definition will mean more precise measurements, especially at smaller masses. "We can now measure mass at any point on the scale rather than extrapolating from the kilogram," said Haddad. "With the Kibble balance, we can go directly to the gram or milligram level." Such precision could help pharmacists measuring personalized doses of medications or astronomers calculating the movements of celestial objects.

China, France, Korea, the United Kingdom, and the United States have all built Kibble balances [7], and the construction of the devices is underway in numerous other countries. "This new definition really is for all times because it is based on a constant baked into the fabric of space-time that won't change in time, and it's for all people because everybody can access it," said NIST physicist Stephan Schlamminger. "So, in a way, we're finishing the arc that started with the French Revolution."

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