Adieu, Le Grand K: The kilogram to be redefined for the first time in 130 years

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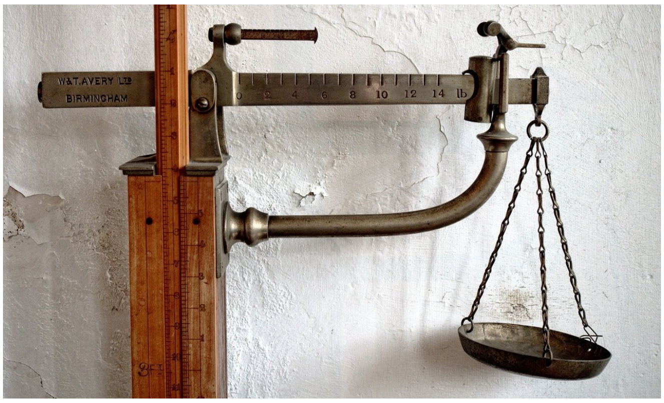

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In a subterranean vault in a suburb of Paris lies a small, rarely seen metal cylinder known as Le Grand K.

For 130 years, this golf-ball-sized hunk of 90% platinum and 10% iridium has served as the international prototype kilogram. That means it was the single physical object by which all other kilograms across the planet were measured.

If microscopic contaminants in the air caused Le Grand K to grow a bit heavier, the kilogram itself grew a bit heavier. If a rigorous cleaning or small scratch caused it to become ever so slightly lighter, the kilogram itself became lighter as well. Indeed, it is estimated that over the course of its lifetime, Le Grand K has lost 50 micrograms of mass.

But the long reign of Le Grand K is about to come to an end.

Starting Monday, the kilogram will be redefined not by another object, but by a fundamental property of nature known as Planck's constant. Like the speed of light, the value of Planck's constant cannot fluctuate—it is built with exquisite precision into the very fabric of the universe.

"Unlike a physical object, a fundamental constant doesn't change," said Stephan Schlamminger, a physicist at the National Institute of Standards and Technology (NIST) in Gaithersburg, Md. "Now a kilogram will have the same mass whether you are on Earth, on Mars or in the Andromeda galaxy."

Researchers who have devoted their lives to the science of measurement say the new definition of the kilogram—and similar changes to the mole (which measures quantities of very small particles), the ampere (which measures electrical charge) and the kelvin (which measures temperature) - represents a profound turning point for humanity.

"The ability to measure with increasing accuracy is part of the advancement of our species," said Walter Copan, director of NIST.

Most of us regular folks will hardly notice the switch. A 4-pound chicken (1.81437 kilograms) at the grocery store or a pound of coffee beans (0.453592 kg) at Starbucks will remain exactly the same.

"We don't want to shock the system," Schlamminger said.

The decision to redefine four base units of the International System of Units was made in November at the 26th General Conference on Weights and Measures in Versailles, France. Delegates from 60 member states assembled in a large auditorium for the historic vote. It was unanimous. A standing ovation and champagne toast followed.

"The meeting itself was an electric experience," said Copan, who represented the U.S. "It was a long journey to get to this point."

The origins of the metric system date back to the

French Revolution in the late 1700s. At the time, an estimated 250,000 different units of measurement were being used in France, making commerce and trade a challenge. The new system was designed to be rational and universal, with units based on properties of nature rather than royal decree or the whims of local dukes and magistrates.

"The idea was that these measurements would be eternal and the same for everybody, everywhere," said Ken Alder, a science historian at Northwestern University in Evanston, Ill.

The foundational unit of the system was the meter, which was supposed to be one ten-millionth the distance from the North Pole to the equator along the Paris meridian. (Scientists at the time made a slight error in their measurements, and the meter is about 2 millimeters longer than it should be.)

At the same time, the kilogram was defined as the mass of 1,000 cubic centimeters of water at 4 degrees Celsius.

These units were adopted by the French Republic in 1795, although in practice, people continued to use their own local measurements for decades.

"It's not like everyone jumped on the bandwagon as soon as the metric system was formalized," said Barry Taylor, a scientist emeritus at NIST. "That was definitely not the case."

Countries in Europe and South America adopted the metric system throughout the 19th century. In 1875, delegates from the U.S. and 16 other countries signed the Treaty of the Meter in Paris. It established a universal system of units based on the meter, the kilogram and the second that would streamline trade among nations. (The second was defined as 1/86,400 of the average time it takes for Earth to complete a single rotation on its axis.)

Although the meter and the kilogram were based on the size of Earth, they were officially defined by metal artifacts, including Le Grand K, that were cast in London in 1889 and kept in a vault in the basement of the newly created International Bureau of Weights and Measures in Sevres, France. Member nations received one of 40 precise replicas.

The Treaty of the Meter also established the General Conference on Weights and Measures (CGPM), an international group tasked with studying and voting on proposed changes to units of measurement for all member states.

"Metrology is a living science," Schlamminger said.

The CGPM approved three more base units in 1954—the ampere for electrical current, the kelvin for thermodynamic temperature and the candela for luminous intensity.

In 1967, it redefined the second based on the oscillations of a cesium-133 atom—a much more precise and dependable pendulum than Earth's slightly wobbly rotation.

In 1983, the meter became the first metric unit tied to a fundamental property of the universe when it was redefined as the distance traveled by light in a vacuum in {99,792,458 of a second.

"Today we can measure the distance from the Earth to a satellite 6 kilometers away to the exquisite precision of 6 millimeters," Schlamminger said. "Try that with a meter stick."

And yet the kilogram remained tethered to the mass of Le Grand K, an object so precious it was removed from its triple-locked vault only once every 40 years for cleaning and calibration.

Metrologists have longed to update the definition of the kilogram since the early 1900s, but the ability to measure Planck's constant with the necessary precision materialized only recently.

Planck's constant is a number that relates the energy and frequency of light, sort of like how pi relates the circumference and diameter of a circle. The technological advances that fixed the value of the constant came in fits and starts.

In the 1970s, scientists at Britain's National Physical Laboratory developed a new type of scale that relates mass to electromagnetic force. It was named the Kibble balance in honor of its inventor, Bryan Kibble, and although it was not yet accurate enough to redefine the kilogram, it suggested a path forward.

By 2005, measurements made with the Kibble balance had improved enough that a group of researchers known among metrologists as the Gang of Five wrote a paper titled, "Redefinition of the kilogram: a decision whose time has come."

"That paper really started this whole odyssey," Schlamminger said.

In 2013, experts agreed that to change the definition, national metrology institutes would need to measure Planck's constant to a precision of 20 parts per billion, and show that two different methods of taking the measurement would produce the same answer.

"One experiment could have a hidden defect, but if you have two absolutely different approaches and they agree, then the chances that you are completely wrong is very low indeed," said Ian Robinson, a researcher at the National Physics Laboratory.

Kibble balances provided one value. The other measurement involved a softball-sized sphere of pure enriched silicon. The structure of the 1-kilogram sphere, and the atoms inside it, allowed scientists to precisely measure Avogadro's constant, which relates the number of atoms or molecules in a substance to its mass. That was used to determine Planck's constant with the help of well-understood equations.

"The silicon sphere served as a check on the Kibble balance approach," Taylor said.

A similar philosophy of using fixed constants underlies the new definitions of the mole, the kelvin and the ampere. After Monday, the mole will be defined by the value of Avogadro's constant, the kelvin by the value of the Boltzmann constant (which relates temperature to energy), and the ampere by the value of the elementary charge, the smallest observable charge in the universe.

"Everyone has access to these fundamental constants," Schlamminger said. "They don't discriminate between rich and poor. All you need is a bit of physics."

Nor do they discriminate between Earthlings and beings elsewhere in the universe. Just as the first iteration of the metric system streamlined communication and trade among nations, the newly defined units could one day help humanity communicate with extraterrestrials, scientists said.

"If we make contact with aliens, what are we going to talk to them about? Physics. There is nothing else," Schlamminger said. "But if you tell aliens that our units of measurement are based on a hunk of metal, you will be the laughingstock of the galaxy."

Scientists don't know how the new units will affect future discoveries, but it is certainly possible they will. For example, the second can now be measured so precisely that researchers can detect small changes in the Earth's gravitational field because time moves just a bit faster the farther it gets from a center of gravity.

"Lord Kelvin, one of the leaders in the field of metrology said, 'To measure is to know,'" Copan said. "As we are able to measure with increasing precision, we are able to learn more about the fundamentals of our universe and the fundamentals of life."

Robinson said that the new definitions will allow scientists to open up their imaginations around the possibilities of measurement.

"From now on, they don't have to think about this lump of platinum and iridium in Paris—they just have to think about physics," he said.

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