How much does a kilogram weigh?

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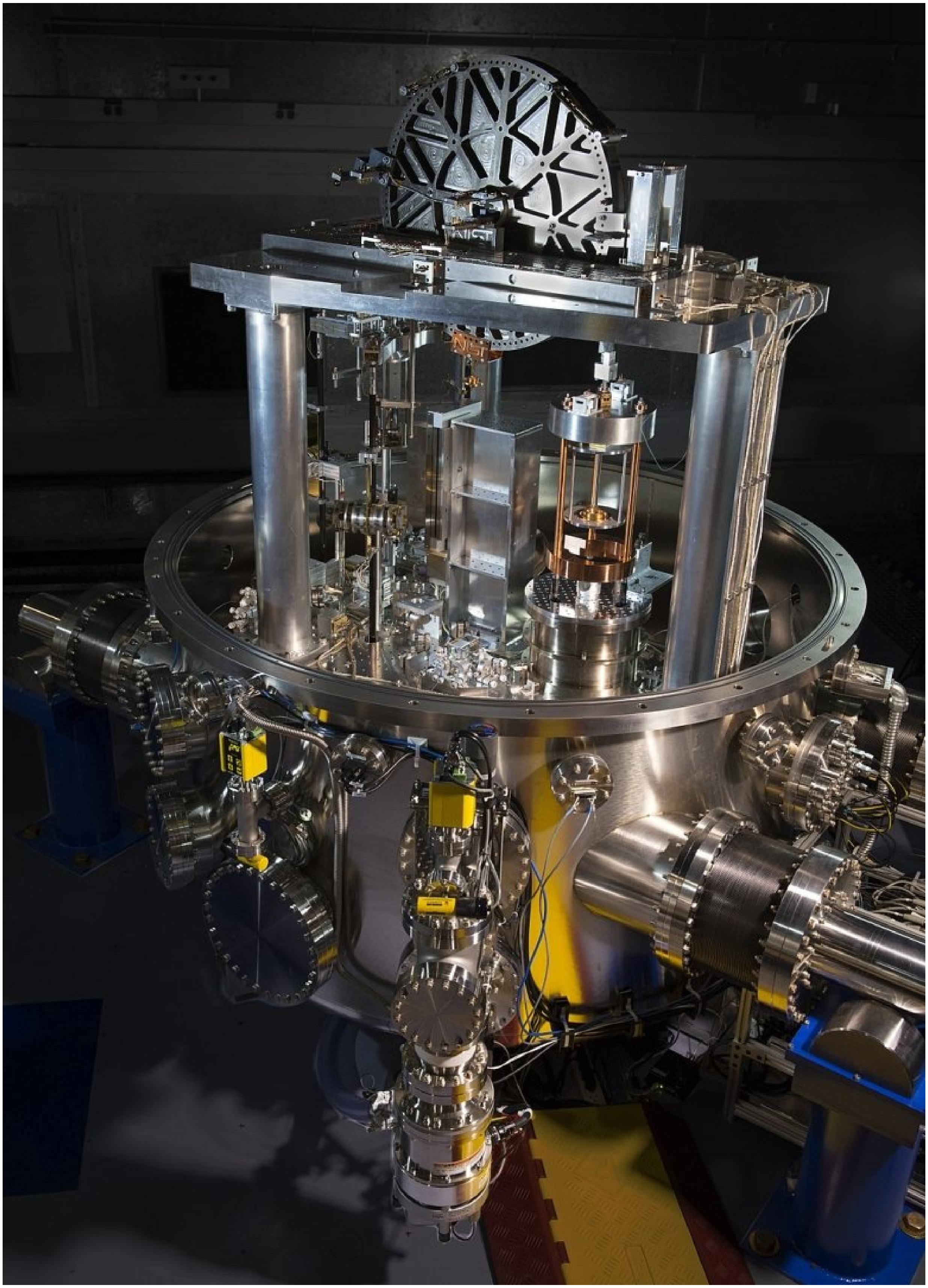

The National Institute of Standards and Technology (NIST)-4 Kibble balance measured Planck's constant to within 13 parts per billion in 2017, accurate enough to assist with the redefinition of the kilogram. Credit: J. L. Lee/NIST

The kilogram doesn't weigh a kilogram any more. This sad news was announced during a seminar at CERN on Thursday, 26 October by Professor Klaus von Klitzing, who was awarded the 1985 Nobel Prize in Physics for the discovery of the quantised Hall effect. "We are about to witness a revolutionary change in the way the kilogram is defined," he declared.

Together with six other units – metre, second, ampere, kelvin, mole, and candela – the kilogram, a unit of mass, is part of the International System of Units (SI) that is used as a basis to express every measurable object or phenomenon in nature in numbers. This unit's current definition is based on a small platinum and iridium cylinder, known as "le grand K", whose mass is exactly one kilogram. The cylinder was crafted in 1889 and, since then, has been kept safe under three glass bell jars in a high-security vault on the outskirts of Paris. There is one problem: the current standard kilogram is losing weight. About 50 micrograms, at the latest check. Enough to be different from its once-identical copies stored in laboratories around the world.

To solve this weight(y) problem, scientists have been looking for a new definition of the kilogram.

At the quadrennial General Conference on Weights and Measures in 2014, the scientific metrology community formally agreed to redefine the kilogram in terms of the Planck constant (h), a quantum-mechanical quantity relating a particle's energy to its frequency, and, through

Einstein's equation E = mc2, to its mass. Planck's constant is one of the fundamental numbers of our universe, a quantity fixed universally in nature, such as the speed of light or the electric charge of a proton.

Planck's constant will be assigned an exact fixed value based on the best measurements obtained worldwide. The kilogram will be redefined through the relationship between Planck's constant and mass.

Replica of the national prototype kilogram standard no. K20 kept by the US government National Institute of Standards and Technology (NIST), Bethesda, Maryland. Credit: National Institute of Standards and Technology

"There's nothing to be worried about," says Klaus von Klitzing. "The new kilogram will be defined in such a way that (nearly) nothing will change in our daily life. It won't make the kilogram more precise either, it will just make it more stable and more universal."

However, the redefinition process is not that simple. The International Committee for Weights and Measures, the governing body responsible for ensuring international agreement on measurements, has imposed strict requirements on the procedure to follow: three independent experiments measuring the Planck constant must agree on the derived value of the kilogram with uncertainties below 50 parts per billion, and at least one must achieve an uncertainty below 20 parts per billion. Fifty parts per billion in this case equals approximately 50 micrograms – about the weight of an eyelash.

Two types of experiment have proved able to link the Planck constant to mass with such extraordinary precision. One method, led by an international team known as the Avogadro Project, entails counting the atoms in a silicon-28 sphere that weighs the same as the reference kilogram. The second method involves a sort of scale known as a watt (or Kibble) balance. Here, electromagnetic forces are counterbalanced by a test mass calibrated according to the reference kilogram.

And that's where the important discovery made by Klaus von Klitzing in 1980, which earned him the Nobel Prize in Physics, comes into play. In order to get extremely precise measurements of the current and voltage making up the electromagnetic forces in the watt balance, scientists use two different quantum-electrical universal constants. One of these is the von Klitzing constant, which is known with extreme precision, and can in turn be defined in terms of the Planck constant and the charge of the electron. The von Klitzing constant describes how resistance is quantised in a phenomenon called the "quantum Hall effect", a quantum-mechanical phenomenon observed when electrons are confined in an extra-thin metallic layer subjected to low temperatures and strong magnetic fields.

"This is truly a big revolution," von Klitzing says. "In fact, it has been dubbed the biggest revolution in metrology since the French Revolution, when the first global system of units was introduced by the French Academy of Sciences."

CERN is playing its part in this revolution. The Laboratory participated in a metrology project launched by the Swiss Metrology Office (METAS) to build a watt balance, which will be used to disseminate the definition of the new kilogram through extremely precise measurements of the Planck constant. CERN provided a crucial element of the watt balance: the magnetic circuit, which is needed to generate the electromagnetic forces balanced by the test mass. The magnet needs to be extremely stable during the measurement and provide a very homogenous magnetic field.

Provided by CERN