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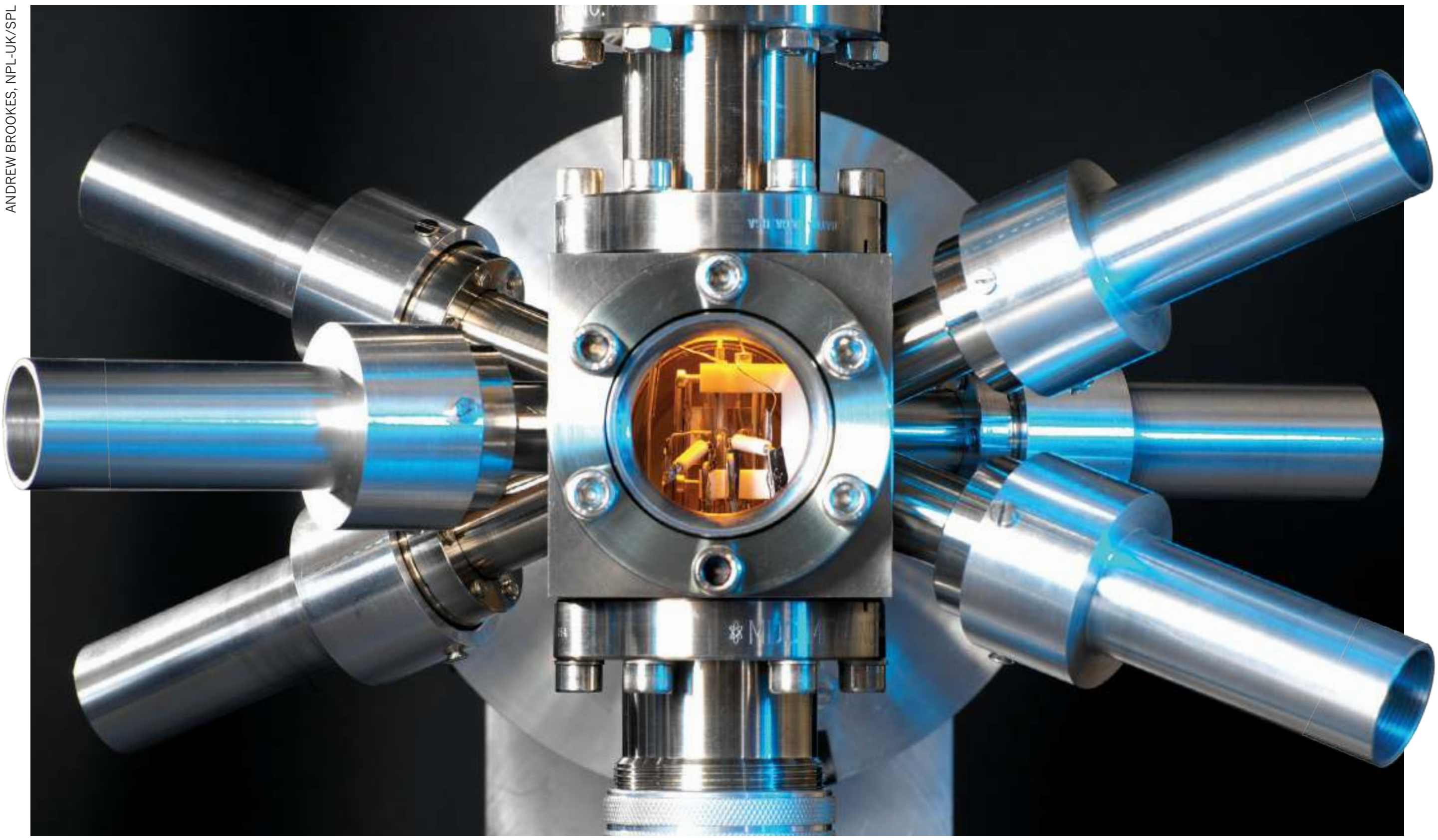

The strontium clock is among the instruments that might be used to define the second in the near future.

MEASUREMENT

Metrologists ditch last physical standard units

Meet the new ampere, kilogram, kelvin and mole, now courtesy of nature's constants.

BY ELIZABETH GIBNEY

In the biggest overhaul of the international system of measurement since 1875, 60 delegates from governments around the world have voted to redefine four basic units — the ampere, the kilogram, the kelvin and the mole. The new definitions will come into force on 20 May 2019. The unanimous 16 November vote at the General Conference on Weights and Measure in Versailles, France, was met with a standing ovation and champagne. "This is big," says Zeina Kubarych, a metrologist at the US National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. "It's the best thrill ride you can get in metrology."

Under the new International System of Units (known simply as SI), all measures will be described using fundamental constants of nature and be derived through experiments, severing the last links between the SI and physical objects or arbitrary references.

The move allows units to be generated from their definition anywhere in the world, and to remain unassailably stable. The vote is the culmination of decades of work, and a triumph for metrologists. It means that the antique, palm-sized cylinder of metal 'Le Grand K', which resides in a vault in Sèvres on the outskirts of Paris will lose its special status as the entity that has defined the kilogram since 1889.

These changes do not mean that the SI system is perfect. Metrologists will now ▶

turn their attention to tying the definition of the second to more-precise clocks, and potentially add more units to the system. "It's like at the end of the Harry Potter series. Good triumphs, but everything's just trashed," says David Newell, a physicist at NIST. In the SI, he adds, "there's still a whole load of mess that still needs to be cleaned up".

FOCUS ON THE CONSTANT

Measurements must always be made against a reference, and standard references ensure that units are comparable and consistent across the world — from measuring milligrams of drugs to the timing of Global Positioning Systems. The idea of basing all units on constants of nature has been around since the late nineteenth century. But it has taken almost 150 years for scientists to measure the values with enough accuracy to do so.

Metrologists working on electricity have refined experiments that count the flow of individual electrons, allowing them to use the charge on a single such particle to determine the ampere — replacing a definition that is based on a hypothetical experiment involving two infinitely long wires, which in reality can only be approximated. The kelvin will soon be defined by the Boltzmann constant, which links energy and temperature, rather than in reference to conditions at a specific temperature of water, known as the triple point.

Meanwhile, the mole — long measured as the number of atoms in 0.012 kilograms of carbon-12 — will soon equal the number of particles specified by Avogadro's number.

In the case of the kilogram, redefinition meant measuring with exquisite precision Planck's constant, a number that defines the size of packets of energy at the quantum scale. One method, known as a Kibble balance, derives Planck's constant by weighing a known mass against an electromagnetic force. Another counts the atoms in two spheres of silicon-28 to derive a value for Avogadro's number, which is converted to Planck's constant.

Teams applying the two different methods only reached values that were accurate and in close enough agreement in 2015. "The fact that they agree to a few parts in 10 million is absolutely extraordinary, as they are definitions based on completely different areas of physics," says Terry Quinn, former head of the International Bureau of Weights and Measures (BIPM).

"It's like the end of the Harry Potter series. Good triumphs, but everything's just trashed."

Because physical artefacts are vulnerable to being lost or damaged, the change makes the mass definition more reliable. Although Le Grand K has, by definition, always weighed exactly 1 kilogram, its mass has changed slightly relative to copies. It has been impossible to say whether Le Grand K loses or gains atoms, but future studies should now reveal that. A beauty of the system is that any experiment — once international comparisons have shown it to be accurate — can be used to determine the unit, says Estefanía de Mirandés, a metrologist at the BIPM. This not only makes the system more democratic, it also 'future-proofs' the definitions, so that they can be used with more-precise experiments in the future, she says, potentially unlocking new technologies. Already, it allows measurements of very large and very small masses with much greater precision than today, she explains.

The second is currently described in relation to the frequency of microwave light absorbed and emitted by caesium-133 atoms. These atoms are now surpassed by 'optical clocks', which use different atoms that interact with higher-frequency visible light and seem to be able to keep time with less error: just 1 second over the age of the Universe. To update the definition of the second in 2026, as many metrologists hope will happen, the community will need to develop methods to compare optical clocks around the world and decide which atom, or atoms, to use as the standard.

Another bugbear that metrologists might try to resolve is finding a smoother way to include dimensionless quantities — such as the radian, the ratio of the length of an arc of a circle to its radius — in the SI system. "In some communities, there's a huge push for that," says de Mirandés.

For the BIPM, which was founded in 1875 to host the physical kilogram and metre standards, the SI revolution is bittersweet. Speakers at the meeting cheerfully quipped that there is no need to go to Paris any more. The BIPM now hopes to forge a role making comparisons between worldwide realizations of units, to ensure their accuracy, says de Mirandés. "It's the end of a period, but also the start of a new one." ■

POLITICS

Brexit divorce deal divides politicians and scientists

Draft treaty confirms Britain will leave European nuclear body — but uncertainties remain.

BY ELIZABETH GIBNEY & HOLLY ELSE

After two years of negotiations, the first real glimmers of what Brexit might involve have emerged. On 14 November, the Cabinet, the UK government's senior decision-making body, backed a draft agreement that defines the terms of the country's withdrawal from the European Union.

For science, many of the specifics that will be most relevant are still to be thrashed out. The 585-page exit treaty, if approved, largely confirms previous commitments made by the UK government, and mostly outlines what will happen during the transition period that begins after Britain leaves the bloc on 29 March 2019 and finishes at the end of 2020.

The text offers details on the future of nuclear regulation in the United Kingdom — but it has little to say on immigration or how access to valuable EU research funds might change. These details are likely to form part of a later agreement that will define the future UK–EU relationship, and which will be negotiated only after March 2019.

An outline of the structure of this relationship, sketched out in a short accompanying document, hints at the possibility of visa-free travel for short visits to and from EU countries after Brexit — encouraging news for researchers who are used to travelling for collaborations and conferences.

WHAT'S IN THE EXIT DEAL?

Hammered out in fraught negotiations with EU officials, the withdrawal agreement would allow EU citizens currently living in Britain, and their families, to claim permanent residence. This should ease fears expressed by many EU nationals resident in the country, including many scientists, that they would have to leave their jobs after Brexit.

The agreement also confirms that Britain will leave the European Atomic Energy Community, Euratom, when it pulls out of the EU.