MEASUREMENT SYSTEMS

New definitions of scientific units are on the horizon

Metrologists are poised to change how scientists measure the Universe.

BY ELIZABETH GIBNEY

Revamped definitions of scientific units are on their way. In the biggest overhaul of the international system of units (SI) since its inception in 1960, a committee is set to redefine four basic units — the ampere, the kilogram, the kelvin and the mole — using relationships to fundamental constants, rather than abstract or arbitrary definitions. The International Bureau of Weights and Measures is reviewing the plans at a meeting near Paris from 16 to 20 October. Its recommendations will then go before the General Conference on Weights and Measures, which oversees the SI system, in November 2018. The changes would take effect in May 2019.

The kilogram is currently defined as the mass of a chunk of metal in a vault in Paris. And an imaginary experiment involving the force between two infinite wires defines the ampere, the unit of electrical current. In the future, these units will be calculated in relation to constants — for example, the ampere will be based on the charge of an electron.

Redefinition might not affect everyday measurements, but it will enable scientists working at the highest level of precision to do so in multiple ways, at any place or time and on any scale, without losing accuracy.

ALL CHANGE

Under the revised SI system, every unit will be defined in relation to a constant, whose value will become fixed. Many of the units will be defined in relation to each other: for example, definition of the kilogram requires Planck's constant, and definitions of the second and metre.

→ Dependency

SECOND (s)

Measures: Time
Requires: Hyperfine-transition frequency of the caesium-133 atom
Definition: Duration of 9,192,631,770 cycles of the radiation corresponding to the transition between two hyperfine levels of caesium-133

METRE (m)

Measures: Length
Requires: Speed of light
Definition: Length of the path travelled by light in a vacuum in 1/299,792,458 seconds

KILOGRAM (kg)

Measures: Mass
Requires: Planck's constant
Definition: One kilogram is Planck's constant divided by $6.626\,070\,15 \times 10^{-34}$ $m^{-2}s$

AMPERE (A)

Measures: Current
Requires: Charge on the electron
Definition: Electric current corresponding to the flow of $1/(1.602\,176\,634 \times 10^{-19})$ elementary charges per second

MOLE (mol)

Measures: Amount of substance
Requires: Avogadro's constant
Definition: Amount of substance of a system that contains $6.022\,140\,76 \times 10^{23}$ specified elementary entities

KELVIN (K)

Measures: Temperature
Requires: Boltzmann's constant
Definition: equal to a change in thermal energy of $1.380\,649 \times 10^{-23}$ joules

CANDELA (cd)

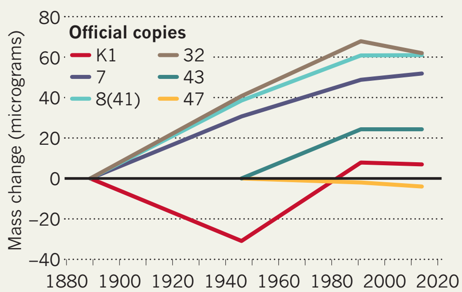
Measures: Luminous intensity
Requires: Luminous efficacy of monochromatic light of frequency 540×10^{12} Hz
Definition: Luminous intensity of a light source with frequency 540×10^{12} Hz and a radiant intensity of 1/683 watts per steradian

THE PROBLEM

For measurements on conventional scales, existing definitions of SI units suffice. But they are poor tools for modern science at the extremes. And basing units on specific points or materials can be troublesome and inelegant, say metrologists.

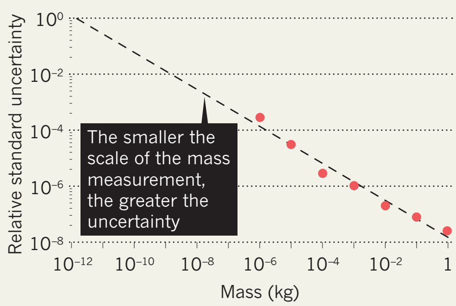
THE UNSTABLE KILOGRAM

The kilogram is currently defined by a lump of platinum-iridium, stored in a vault near Paris. Because objects can easily lose atoms or absorb molecules from the air, using one to define an SI unit is problematic. Compared to the prototype, some official copies have gained at least 50 micrograms over a century.



A QUESTION OF SCALE

When a unit is defined on a fixed scale, uncertainties grow larger the further scientists move away from that point. Currently, for example, measurements in milligrams have a minimum relative uncertainty 2,500 times that associated with the kilogram. The problem disappears under the proposed system, which relies on constants to define units.



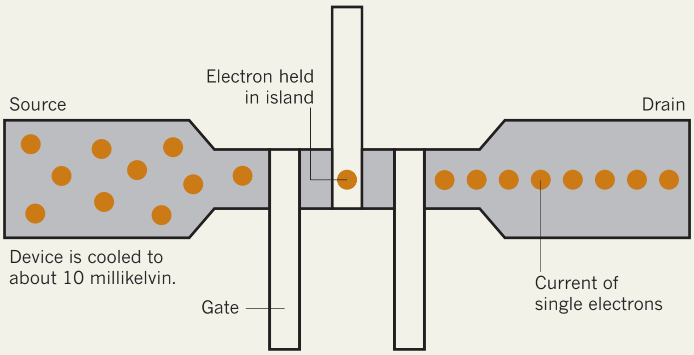
SOURCE: SHAW, G. *ET AL. METROLOGIA* **53,** A86–A94 (2016).

THE TECHNIQUES

Under the revamped SI system, researchers will be able to use various experiments to relate constants to each of the units measured.

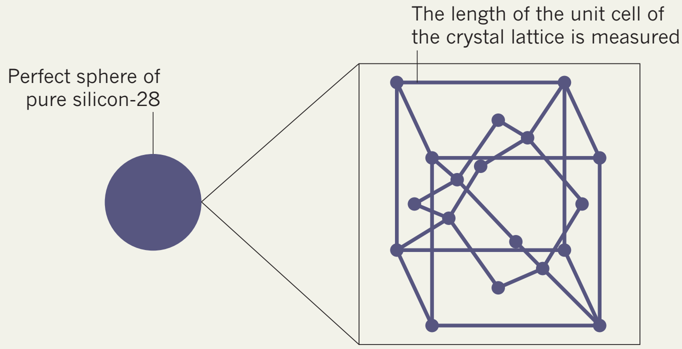
AMPERE: THE SINGLE-ELECTRON PUMP

Used to measure the charge of an electron, an electron pump could become one tool for determining the ampere. By trapping individual electrons as they travel rapidly across a conductor, the pump can generate a measureable current by counting single electrons.



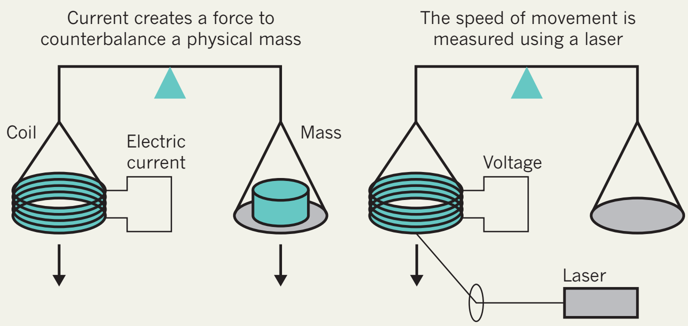
MOLE: THE SILICON SPHERE

As the device that gives scientists Avogadro's constant, this silicon sphere offers a state-of-the-art way to measure a mole. It would determine the precise number of atoms in a perfect sphere of pure silicon-28. Researchers do this by using lasers to measure the length of a unit of the sphere's crystal lattice, and its mean diameter.



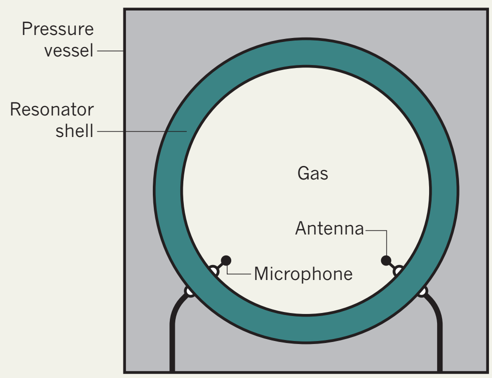
KILOGRAM: THE WATT BALANCE

The Watt balance compares mechanical power with electromagnetic power using two separate experiments. First, a current is run through a coil in a magnetic field to create a force that counterbalances a known physical mass. Then, the coil is moved through the field to create a voltage. By measuring the speed as well as experimental values that relate the voltage and current to Planck's constant, scientists can precisely determine the weight of a mass in kilograms.



KELVIN: ACOUSTIC THERMOMETRY

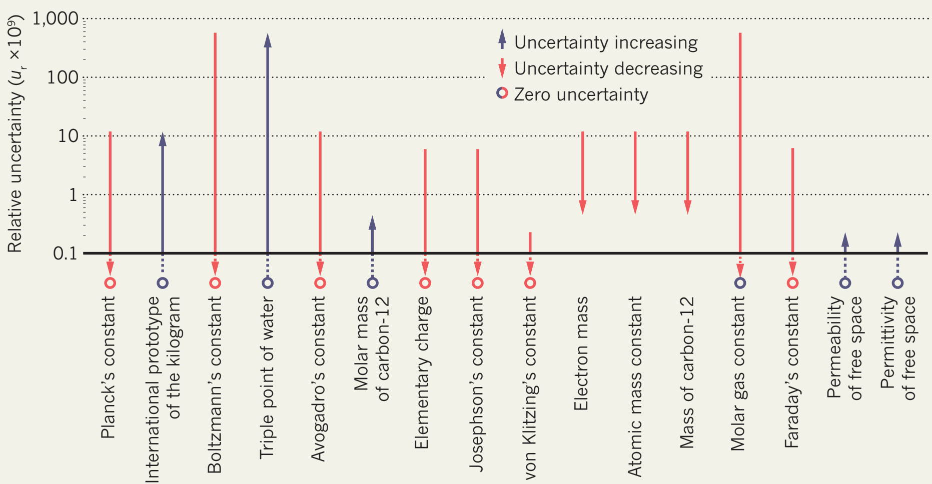
This technique could be used to derive precise temperature measurements. The speed of sound in a gas-filled sphere (which is proportional to the average speed of the atoms in it) can be determined at a fixed temperature, by analysing the frequency of sound waves that resonate within in it and measuring the sphere's volume.



THE FUTURE

Experimental teams have been working for decades to agree on values for the constants on which the definitions will soon hinge. They had to meet strict conditions, which the kilogram teams fulfilled only in 2015. All groups submitted final figures by 1 July. Under the new system, these constants will be stripped of their uncertainties and fixed as exact numbers in May 2019. Their former uncertainties will then be transferred to measurements that use the units defined by the constants. As a consequence, other, related constants, once expressed in the new units, will see their uncertainties reduced as well.

The loser will be the mass of the prototype kilogram in Paris. It currently has an uncertainty of zero — but that will soon rise to at least ten parts per billion.



CORRECTION

The News story 'New definitions of scientific units are on the horizon' (*Nature* **550,** 312–313; 2017) incorrectly gave the unit in the definition of a kilogram as ms^{-2}. The correct unit is $m^{-2}s$. The PDF has also been updated from the original version to include finalized numbers.