# Paving the way for the redefinition of the unit of temperature

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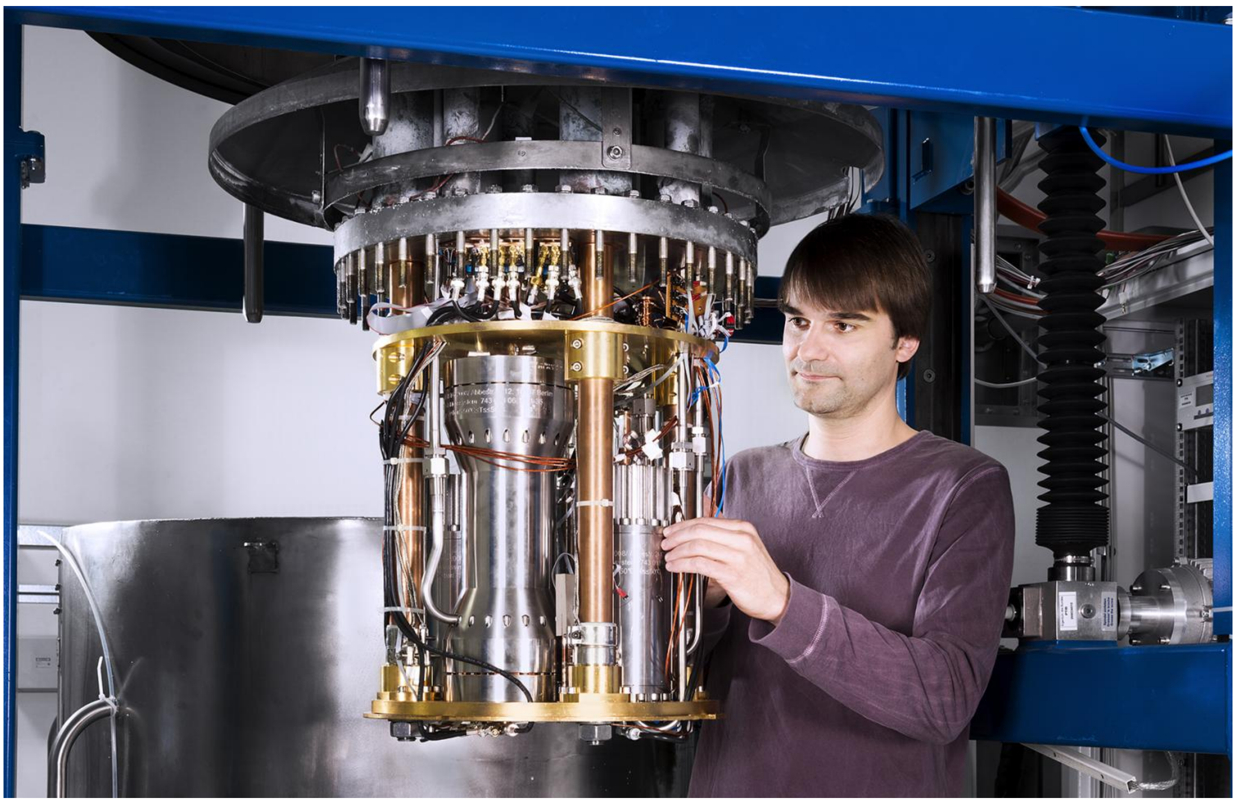

PTB scientist Christof Gaiser with the core of the dielectric-constant gas thermometer. The different silver-colored pressure vessels have special capacitors which are filled with helium to carry out the measurement that takes place inside them. Credit: PTB

At present, the kelvin is literally based on no more than water—on the triple point of water, to be more precise. The base unit of temperature is therefore dependent on a material whose properties may vary. But this is about to change: In the fall of 2018, the kelvin, as well as all the other units of the International System of Units (SI), will be redefined to rest on a solid and invariable foundation consisting of fundamental constants. The kelvin will be based on the Boltzmann constant, which scientists from the Physikalisch-Technische Bundesanstalt (PTB) have now determined by means of a dielectric-constant gas thermometer with such accuracy that all obstacles to the redefinition of the unit of temperature, the kelvin, have been removed. The results have been published in the current edition of the specialist journal *Metrologia*.

Currently, the definition of the SI base unit kelvin is still based on a material property of water: the triple point. At a well-defined temperature, water can simultaneously be a solid, a liquid and a gas. However, because no two waters are alike, the triple point of water depends on the isotopic composition of the water used. Although physicists from all around the world have agreed upon a "standard water", this situation is far from ideal. The kelvin therefore has the same problem as the kilogram or the mole: they are all based on the properties of materials—either on so-called "prototypes" (such as the international prototype of the kilogram, which is a cylinder made of a platinum/iridium alloy) or on water (as in the case of the kelvin). All these materials are variable in many ways. In no more than one and a half years (in the fall of 2018, in all likelihood), the whole International System of Units (SI) will be redefined by a large international conference. From then on, all units will be based on a set of fundamental constants—invariable properties of the physical universe. These constants will then be the "measure of all things" in metrological matters.

The appropriate fundamental constant for temperature measurements is the Boltzmann constant k. It indicates how the thermal energy of a gas (i.e., the movement of the gas particles) depends on the temperature. In a closed vessel, the kinetic energy can be measured by determining the pressure of the gas. This can be done (with the required accuracy) by means of an acoustic gas thermometer. The corresponding measurements performed at the metrology institutes of England, Italy, France, China and the United States have reached a measurement uncertainty of less than 1 ppm (one millionth), thereby fulfilling the first condition laid down by the Consultative Committee for Thermometry (CCT) for the redefinition of the kelvin. Another condition, however, stipulates that a second, independent method reach similarly small measurement uncertainties. For this purpose, PTB launched its dielectric-constant gas thermometer project in 2007, which has now reached 1.9 ppm and thus meets the required accuracy.

This special thermometer exploits the fact that helium, as a rare gas and a dielectric, changes the capacitance of a capacitor. It is therefore possible to measure the density of helium at a given pressure by means of an electric measurement—and via density, to measure temperature as well. Moreover, electric capacitance measurements can be carried out with great accuracy. In this case, the measurement uncertainty is only a few parts per billion. However, to reach such accuracy, everything had to be perfectly tuned: the scientists had to determine the material properties of the capacitors at high pressures (up to 7 MPa)—bordering on the impossible—and ensure that the purity of the gas used was better than 99.99999 %. Furthermore, PTB's best standard for pressure measurements, which is based on pressure balances, had to be improved. These developments, which are unique worldwide, could only succeed thanks to various cooperation projects within PTB (especially with the two working groups "Pressure" and "Geometrical Standards") and thanks to large-scale international cooperation.

Now that the Boltzmann constant has been determined with sufficient precision by means of at least two independent methods, CODATA will compute the final value of k in September 2017. The "CODATA Task

Group on Fundamental Constants" is an international group of experts whose task is to assess the values of fundamental constants measured in metrology institutes throughout the world and to bring these values in line with one another. This will pave the way for the redefinition of the kelvin based on a fundamental constant. And in the fall of 2018, we can expect that the motto will be: "Clear the stage for a brand new SI!"

**More information:** Christof Gaiser et al, Final determination of the Boltzmann constant by dielectric-constant gas thermometry, *Metrologia* (2017). DOI: 10.1088/1681-7575/aa62e3

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