The kelvin in the "new SI" - differences between thermodynamic- and ITS-90 temperature - a pathway to improvements in metrology and beyond

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Since the establishment of the International System of Units (SI), extraordinary advances have been made in linking SI units to invariant quantities such as fundamental constants of physics and properties of atoms. Since 2019, the definition of the kelvin is based on a fixed numerical value of the Boltzmann constant k. The effect of the new definition of the kelvin is that one kelvin is equal to the change of thermodynamic temperature T resulting in a change of thermal energy kT by 1.380649 x 10^{-23} J. It implies the equivalence of mechanical and thermal energy. Thus, k is simply the conversion factor between energy and temperature.

Since 2019, the Mise en pratique for the definition of the kelvin (MeP-K) [1] allows for both the realization and dissemination of thermodynamic temperature T as well as its approximation (T_{90}), the temperature according to the International Temperature Scale of 1990, ITS 90. An improved knowledge of the differences (T-T_{90}) is therefore of eminent importance. In 2011, a working group of the Consultative Committee for Thermometry published their best estimates of (T-T_{90}). Since 2011, the work on the determination of the Boltzmann-constant [2] has stimulated significant improvements in primary thermometry. A recent paper [3] updates the (T-T_{90}) estimates by combining and analyzing the data used for the 2011 estimates and data from more recent primary thermometry. The new data has been obtained by four types of gas thermometry: acoustic, dielectric constant, refractive index, and constant volume. Their uncertainty estimates are now comparable with the uncertainties in the best measurements of thermodynamic temperature values and the uncertainties in ITS 90 realizations.

For users without primary thermometry capability, it is now possible to access thermodynamic temperature values T below 335 K with comparably small uncertainties via an ITS 90 calibration and the transfer applying (T-T_{90}). This is a way to bridge the existing gap between enormous effort for T measurements and comparably good access to T_{90}. The applications in this field are divers and increase with demands for decreasing uncertainties. An example in metrology is the prospering field of alternative pressure standards with T as one of the key parameters. The idea, first expressed in [4], is now tested on a level of 2 ppm [5] at the triple-point-of-water temperature T_{TPW}. This is only possible if T is known on the 1 ppm level which is comparably easy to achieve at T_{TPW}. However, pressure standards are usually operated at room temperature. For such applications, the existing difference (T-T_{90}) of order 3 mK must be known with very small uncertainties. Another example is the field of thermophysical properties where ab initio calculations of gas properties have made enormous progress. To check the theory by experiment, highly accurate measurements are needed. But theory evidently is based on T, whereas the experiments are made with thermometers carrying T_{90}. In the future, it is very likely that the group of users will increase, and with new measurements in the temperature range above 335 K, the range of low uncertainty (T-T_{90}) estimates will be extended.

References

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