Statement concerning the redefined kelvin and the implications for thermometry

This briefing document describes the background and implications of the redefinition of the kelvin, which is the base unit of the thermodynamic temperature in the International System of Units (SI). The document is prepared by EURAMET EMPIR Implementing the new kelvin 2 (InK2) project consortium and it is aimed for circulation to the accreditation bodies, accredited laboratories and other stakeholders.

On November 16th 2018 at the 26th meeting of the General Conference on Weights and Measures (CGPM) in Versailles, France, the member states of the Bureau International des Poids et Mesures (BIPM) voted and agreed to revise the SI [1]. In the revision, all seven SI base units will be defined in terms of fixed values of seven fundamental constants of nature. The revision will assure the future stability of the SI-system and open the opportunity for developing and using new technologies to realise the definitions.

From 1954 to 2018, the kelvin was defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water, T_{TPW}. Although the numerical value of the T_{TPW} is fixed to be exactly 273.16 K, the temperatures produced by triple point of water cells depend in practice on for example the purity and isotopic composition of the water used. In addition, the kelvin realisation, based on the temperature of the water triple point is not very practical at the lowest (below 25 K) and at the highest (above 1300 K) temperatures and the attainable measurement accuracy is limited at the temperature extremes by the definition.

Direct measurement of thermodynamic temperature requires a primary thermometer. Unfortunately, primary thermometry is usually complicated and time consuming. As a practical alternative, the defined International Temperature Scales provide internationally accepted procedures for both realizing and disseminating temperature in a straightforward and reproducible manner. Currently, the International Temperature Scale of 1990 (ITS-90) [2] is in use at the temperatures above 0.65 K and Provisional Temperature Scale of 2000 (PLTS-2000) [3] in the temperature range from 0.9 mK to 1 K.

The new definition of the kelvin, which came into force on May 20th 2019, is as follows:

> The kelvin, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant k to be $1.380\,649 \times 10^{-23}$ when expressed in the unit J K^{-1} , which is equal to kg m^2 s^{-2} K^{-1}, where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$.

(h is the Planck constant, c is the speed of light in vacuum and $\Delta\nu_{Cs}$ is the caesium frequency corresponding to the transition between the two hyperfine levels of the unperturbed ground state of the ^{133}Cs atom.) This definition implies the exact relation $k = 1.380\,649 \times 10^{-23}$ J/K. Its effect is that one kelvin is equal to the change of thermodynamic temperature T that results in a change of thermal energy kT by $1.380\,649 \times 10^{-23}$ J.

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The new definition of the kelvin is independent from any material properties and it does not imply any particular method or experiment for its practical realization. In the light of the redefinition, and to ensure continuing global uniformity in temperature measurement, a flexible document, referred to as the *Mise en Pratique* for the definition of the kelvin (*MeP*-K) [4] has been prepared by the Consultative Committee for Thermometry (CCT)[1]. This document incorporates the two current temperature scales but also provides for the development of primary thermometry methods for sensor calibration and traceability purposes.

Although the kelvin redefinition will fundamentally change the principles and practice of thermometry, in the short term very little will change from the point of view of the most end users. The status and contents of the International Temperature Scales will remain unchanged. The temperature calibrations performed according to the ITS-90 and PLTS-2000 will be valid and traceable to the SI after the kelvin redefinition. In order to communicate the redefined kelvin to a broad audience, the CCT has prepared a statement [5] for their stakeholders addressing the changes expected under the redefined kelvin:

> "The kelvin has been redefined with no immediate effect on temperature measurement practice or on the traceability of temperature measurements, and for most users, it will pass unnoticed. The redefinition lays the foundation for future improvements. A definition free of material and technological constraints enables the development of new and more accurate techniques for making temperature measurements traceable to the SI, especially at extremes of temperature. The guidance on the practical realization of the kelvin (i.e. the *MeP*-K) supports its world-wide dissemination by describing primary methods for measurement of thermodynamic temperature and equally through the defined scales ITS-90 and PLTS-2000."

[1] https://www.bipm.org/en/publications/si-brochure/
(The new definitions of all the SI units can be found in this, the 9th edition of the SI brochure, which can be downloaded for free)

[2] H. Preston-Thomas et al. *Metrologia* 27 (1990) 3-10

[3] R. Rusby et al. *J. Low Temp. Physics* 126 (2002) 633-642

[4] https://www.bipm.org/utils/en/pdf/si-mep/SI-App2-kelvin.pdf
(The *MeP*-K is an annex of the 9th brochure of the SI)

[5] https://www.bipm.org/utils/common/pdf/SI-statement.pdf

[1] A consultative committee of the International Committee for Weights and Measures (CIPM).

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