The best determination of the Boltzmann constant k by acoustic thermometry of helium-4 gas

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The SI unit of temperature will soon be redefined in terms of a fixed value of the Boltzmann constant k derived from an ensemble of measurements worldwide. We report on the best-ever and definitive determination of k using acoustic thermometry of helium-4 gas in a 3-litre volume quasi-spherical resonator at LNE-Cnam. The method is based on the accurate determination of acoustic and microwave resonances to measure the speed of sound at different pressures.

The principle of the experiment is as follows. A gas-filled quasi-spherical resonator (QSR) is maintained in a thermostat at a known temperature, here the temperature of the triple point of water $T_{TPW} = 273.16$ K or within a few millikelvin of it (measurements are corrected for the small difference by a temperature ratio, other terms being sufficiently constant at the required level of accuracy). Acoustic resonance measurements are performed at different pressures of helium gas while the radii of the QSR are measured using microwave resonances. Great care is taken to avoid impurities in the test gas: a gas purifying system supplies a continuous flow of pure helium to the resonator to remove outgassing impurities. The amount of the only impurity that cannot be removed by purification, helium-3, is determined by mass spectrometry of samples from the same bottle as that used for the experiment. Correction terms on acoustic and microwave measurements have been computed using carefully validated theoretical models, and applied to the acoustic and microwave signals.

From data and traceable thermometry we deduce the value of universal gas constant $R = 8.3144614(50)$ J·mol^{-1}·K^{-1}. Using the current best available value of the Avogadro constant [1], we obtain $k = 1.38064878(83) \times 10^{23}$ J·K^{-1} with $u(k)/k = 0.60 \times 10^{-6}$, where the uncertainty u is one standard uncertainty corresponding to a 68 % confidence level. This value is consistent with our previous determinations [2, 3, 4] and with that of the 2017 CODATA adjustment of the fundamental constants [5] within the standard uncertainties.

[1] D B Newell *et al.*, 2018 Metrologia **55** L13
[2] L Pitre *et al.*, 2017 Metrologia **54** 856
[3] L Pitre *et al.*, 2015 Metrologia **52** S263
[4] L Pitre *et al.*, 2011 Int J Thermophys **32** 1825
[5] Peter J Mohr *et al.*, 2018 Metrologia **55** 125