Direct comparison of ITS-90 and PLTS-2000 from 0.65 K to 1 K at LNE-Cnam

Fernando Sparasci, Laurent Pitre, Changzhao Pan, Mark Plimmer, Bo Gao
LNE-Cnam, 61 rue du Landy, 93210 La Plaine-Saint Denis, France

Introduction

In the temperature range between 0.65 K and 1 K, the International Temperature Scale of 1990 (ITS-90) [1] is based on the vapour-pressure temperature relation of ^{3}He and overlaps with the Provisional Low Temperature Scale of 2000 (PLTS-2000) [2], defined by the melting pressure of ^{3}He. A comparison carried out at PTB in 2006 revealed differences between the two scales of up to 1.5 mK at 0.65 K [3].

The current (2019) edition of the "*Mise en pratique* for the definition of the kelvin in the SI" [4] considers equivalent both the ITS-90 and the PLTS-2000 between 0.65 K and 1 K, albeit while acknowledging that T_{2000} offers a better approximation of thermodynamic temperature than T_{90} (here T_{2000} represents the temperature obtained using PLTS-2000 and T_{90} that using ITS-90). Such a situation is no longer acceptable and the discrepancy between the two scales needs to be resolved.

A direct comparison T_{90}-T_{2000}, from 0.65 K to 1 K, has been performed at LNE-Cnam [5] with the intention of confirming or otherwise the results obtained by PTB in 2006. The two comparisons employ substantially different methods: the one at PTB was *indirect*, since T_{90} and T_{2000} were realized at different times and compared via transfer standards. The one at LNE-Cnam was a *direct* comparison in which T_{90} and T_{2000} were realized simultaneously in the same measurement apparatus. No transfer standard was required in this case. The results obtained in the two studies are consistent and provide the necessary confirmation that PTB has been expecting from the international community since 2008 (see CCT/08-04 document [6]).

We provide here a short summary of the measurement of T_{90}-T_{2000} published by LNE-Cnam in [5], to stimulate discussion within the CCT, in order to start the necessary process of resolving the discrepancy between ITS-90 and PLTS-2000 in their overlapping temperature range.

Measurement of $T_{90} - T_{2000}$ at LNE-Cnam

To establish a *direct* link between the ITS-90 and the PLTS-2000, starting in 2011, LNE-Cnam has developed a ^{3}He Vapor-Pressure Thermometer (VPT) combined with a ^{3}He Melting Pressure Thermometer (MPT), installed in a dilution refrigerator [7]. With such an apparatus, a direct comparison T_{90}-T_{2000} from 0.65 K to 1 K was carried out on two separate occasions, once in 2019 and, following improvements, again in 2020.

The realization procedures for ITS-90 and PLTS-2000 are those mentioned in the CCT documents available in [8] and [9]. The main study was focused on pressure measurements related to the VPT and MPT. For the VPT, a high-precision differential capacitance manometer traceable to the French national pressure standard was used. The hydrostatic and thermomolecular pressure corrections were studied and quantified, as well as heat load on the pressure line and other minor effects. For the MPT, the relationship between the MPT measured capacitance and the pressure was determined by a two-step calibration process, where traceability was provided by a calibrated piston balance. The hydrostatic pressure correction, hysteresis and long-term stability of the capacitive sensor, pressure minimum correction and other effects were studied. Since the experiment is a *direct* comparison between ITS-90 and PLTS-2000, all the MPT and VPT measurements were conducted simultaneously. A control thermometer and a heater located on the copper platform housing the MPT and the VPT devices were used to set the platform temperature. Once a stable setpoint had been reached, the MPT capacitance and the VPT pressure were recorded at the same time. Each T_{90}-T_{2000} determination was the average of several hours of recordings on the same setpoint, with a standard deviation better than 11 μK at any measured temperature between 0.65 K and 1 K.

$T_{90} - T_{2000}$ results at LNE-Cnam

Figure 1 shows all the results of both runs performed at LNE-Cnam [5] and their weighted average value. The uncertainty bars correspond to standard uncertainties (coverage factor $k=1$). The present results are consistent with those of the pioneering indirect comparison made at PTB [3]. Except for the point around 1 K, all differences are below 0.22 mK and lie within the standard-uncertainties of each laboratory's result.

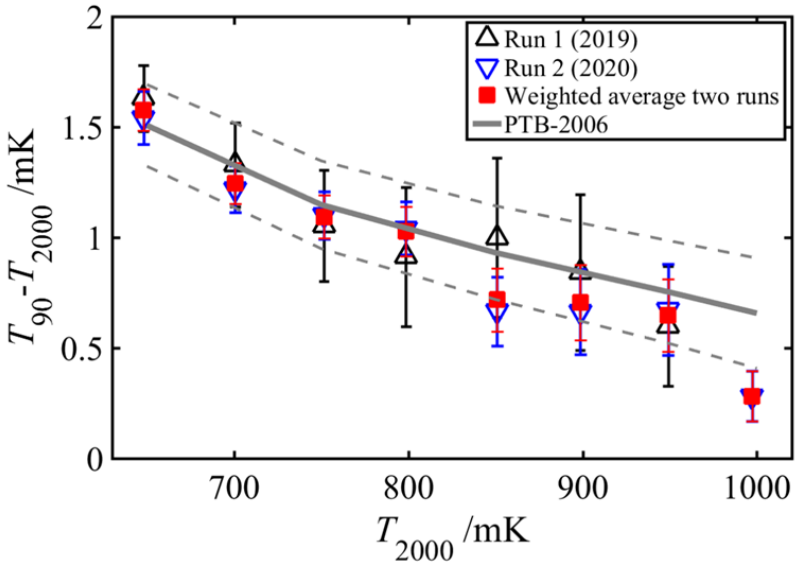

Figure 1. Values of T_{90}-T_{2000} from 0.65 K to 1 K from the present LNE-Cnam work [5] and a comparison with the results obtained at PTB in 2006 [3]. The dashed lines correspond to the combined standard uncertainty of PTB-2006.

Conclusion

The results presented here and more extensively in [5], together with the ones of PTB [3], pave the way to the resolution of the long-lasting discrepancy between ITS-90 and PLTS-2000.

In their publication [3], PTB presented a new vapour-pressure equation for ^{3}He between 0.65 K and 3.2 K (named PTB-2006 [6]), consistent with the thermodynamic temperature within a standard uncertainty of 0.6 mK over the whole range for which it is defined. The proposed equation was intended to be used to combine ITS-90 and PLTS-2000 into a new, unified International Temperature Scale. The recent work of LNE-Cnam confirms the correctness of the underlying data used to elaborate such a new ^{3}He vapour-pressure equation and the discrepancy between ITS-90 and PLTS-2000 to be resolved.

Since neither the establishment of a new temperature scale, nor revisions of the ITS-90 and the PLTS-2000 are planned in the foreseeable future, the authors propose that:

- the CCT takes the necessary actions to elaborate corrections to the ITS-90 between 0.65 K and 1 K, to make T_{90} lie as close to thermodynamic temperature as is T_{2000}.
- the new ^{3}He vapour-pressure equation presented in [3] is used to determine these corrections, which should be finally included into the Technical Annex of the ITS-90 [10], in order to make them mandatory for the realization of T_{90}.

References

1. Preston-Thomas H., Metrologia 27, 3–10 (1990), https://dx.doi.org/10.1088/0026-1394/27/1/002

2. BIPM 2001 Procès-Verbaux des Séances du Comité International des Poids et Mesures vol 68 (Sèvres: BIPM), 89th Meeting of the CIPM, pp. 128–30 (2001), https://www.bipm.org/utils/en/pdf/PLTS-2000.pdf

3. Engert J., Fellmuth B., and Jousten K., Metrologia 44, 40-53 (2007), https://dx.doi.org/10.1088/0026-1394/44/1/006

4. Mise en pratique for the definition of the kelvin in the SI, SI Brochure, 9th edition (2019), Appendix 2, https://www.bipm.org/utils/en/pdf/si-mep/SI-App2-kelvin.pdf

5. Pan C., Sparasci F., Plimmer M., Risegari L., Daugas J-M., Rouillé G., Gao B., Pitre L., "Direct comparison of ITS-90 and PLTS-2000 from 0.65 K to 1 K at LNE-Cnam" Metrologia, Accepted Manuscript online 4 January 2021, https://doi.org/10.1088/1681-7575/abd845

6. J. Engert, B. Fellmuth, "PTB-2006: A new ^{3}He vapor-pressure scale from 0.65 K to 3.2 K consistent with the PLTS-2000", CCT/08-04 (2008), https://www.bipm.org/cc/CCT/Restricted/24/D04_CCT-2008-PTB2006.pdf

7. F. Sparasci, L. Pitre, D. Truong, L. Risegari,·Y. Hermier, "Realization of a ^{3}He–^{4}He Vapor-Pressure Thermometer for Temperatures Between 0.65 K and 5 K at LNE-CNAM", International Journal of Thermophysics, vol. 32, pp 139-152, 2011, https://dx.doi.org/10.1007/s10765-011-0929-7

8. Guide to the Realization of the ITS-90, https://www.bipm.org/en/committees/cc/cct/guide-its90.html

9. Supplementary Information for the Realization of the PLTS-2000, https://www.bipm.org/utils/common/pdf/ITS-90/Guide-PLTS-2000.pdf

10. Technical Annex for the International Temperature Scale of 1990 (ITS-90), https://www.bipm.org/utils/en/pdf/MeP_K_Technical_Annex.pdf