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Estimates of the Differences between Thermodynamic Temperature and the ITS-90

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Abstract

At the CCT's request, Working Group 4 (WG4) critically reviewed all available measurements of $T - T_{90}$ including constant-volume gas thermometry, acoustic gas thermometry, spectral radiation thermometry, total radiation thermometry, noise thermometry, and dielectric-constant gas thermometry. Consensus estimates are provided for $T - T_{90}$, for selected measurements from 4.2K to 1358K, as well as a recommendation for analytic approximations to $T - T_{90}$ for the range 0.65K to 1358K.

Estimates of the Differences between Thermodynamic Temperature and the ITS-90 Contents

1. Table of Differences

Table 1 summarizes the best estimates of $T - T_{90}$ above 4.2K as of 2010. In general, a weighted average was formed using the uncertainties identified by WG4. For details see [1]. The data are shown in Figure 1 and Figure 2.

Table 1. **Estimates of $T - T_{90}$ between 4.2K and 1358K. The transitions of the defining fixed pointsand secondary reference points of the ITS-90 are marked in the 2nd and 6th columns. All uncertainties are standard uncertainties ($k = 1$). The differences for temperatures above 1358K are under investigation by Working Group 5. The results presented here may be extrapolated above 1358K using Planck's law.**

T_{90} (K)		$T - T_{90}$ (mK)	u (mK)	T_{90} (K)		$T - T_{90}$ (mK)	u (mK)
4.2		−0.02	0.12	161.405	Xe	−8.43	1.8
5		0.10	0.12	195		−6.97	1.8
6		0.04	0.13	234.3156	Hg	−3.25	1.0
7		−0.08	0.09	255		−1.64	0.9
8		0.01	0.10	273.16	TPW	0	0
9.288	Nb	0.13	0.11	290		2.19	0.4
11		0.27	0.12	302.9146	Ga	4.38	0.4
13.8033	e-H_2	0.44	0.14	335		7.62	0.5
17.035	e-H_2	0.51	0.16	373.124	H_2O	9.74	0.6
20.27	e-H_2	0.32	0.17	429.7485	In	10.1	0.8
22.5		0.10	0.18	505.078	Sn	11.5	1.3
24.5561	Ne	−0.23	0.20	600.612	Pb	9.21	6.1
35		−0.53	1.0	692.677	Zn	13.8	6.9
45		−0.75	1.4	800		22.4	6.4
54.3584	O_2	−1.06	1.6	903.778	Sb	27.6	7.6
70		−1.57	1.9	933.473	Al	28.7	6.6
77.657		−3.80	1.2	1052.78	Cu/Ag	40.9	26
83.8058	Ar	−4.38	1.3	1150		46.3	20
90		−5.30	1.1	1234.93	Ag	46.2	14
100		−6.19	1.2	1337.33	Au	39.9	20
130		−8.07	1.6	1357.77	Cu	52.1	20

2. Interpolation Functions

If it is not convenient to use Table 1, the differences $T - T_{90}$ may be approximated by the following expressions. Above 70K, the relative differences of the interpolation functions (with respect to the values of Table 1, see p. 7) are less than 15 %, except at 600K and the gold point.

From 0.65K to 2K, use the polynomial for the temperature scale PTB-2006 (based on the ^{3}Helium vapor-pressure) [2] with

$$T - T_{90} \equiv T_{2006} - T_{90}.$$

Below 1K, T_{2006} is identical to $T_{\mathrm{PLTS\text{-}2000}}$.

From 2K to 8K,

$$T - T_{90} \equiv 0.$$

From 8K to 273.16K,

$$(T - T_{90})/\mathrm{mK} = \sum_{i=0.7} b_i \times \left(\log^{10}\left(T_{90}/273.16\mathrm{K}\right)\right)^{i+1} \tag{1}$$

with the coefficients:

$$b_0 = 4.424\,57 \times 10^1 \; b_1 = -1.763\,11 \times 10^2 \; b_2 = -1.539\,85 \times 10^3 \; b_3 = -3.636\,85 \times 10^3$$

$$b_4 = -4.198\,98 \times 10^3 \; b_5 = -2.613\,19 \times 10^3 \; b_6 = -8.419\,22 \times 10^2 \; b_7 = -1.103\,22 \times 10^2$$

The derivative d $(T - T_{90})/\mathrm{d}T_{90}$ at the triple point of water is 7.0×10^{-5}.

From 273.16K to 1357.77K (copper point):

$$(T - T_{90})/\mathrm{mK} = (T_{90}/\mathrm{K}) \sum_{i=0.4} c_i \times \left(273.16\mathrm{K}/T_{90}\right)^{2i} \tag{2}$$

with the coefficients:

$$c_0 = 0.0497 \; c_1 = -0.3032 \; c_2 = 1.0254 \; c_3 = -1.2895 \; c_4 = 0.5176$$

The derivative at the triple point of water is 10.1×10^{-5}, resulting in a discontinuity of 3.1×10^{-5} between Equation (1) and Equation (2), see Figure 1. This is consistent with the values from recent thermodynamic measurements and measurements of platinum resistance thermometers that conform to ITS-90.

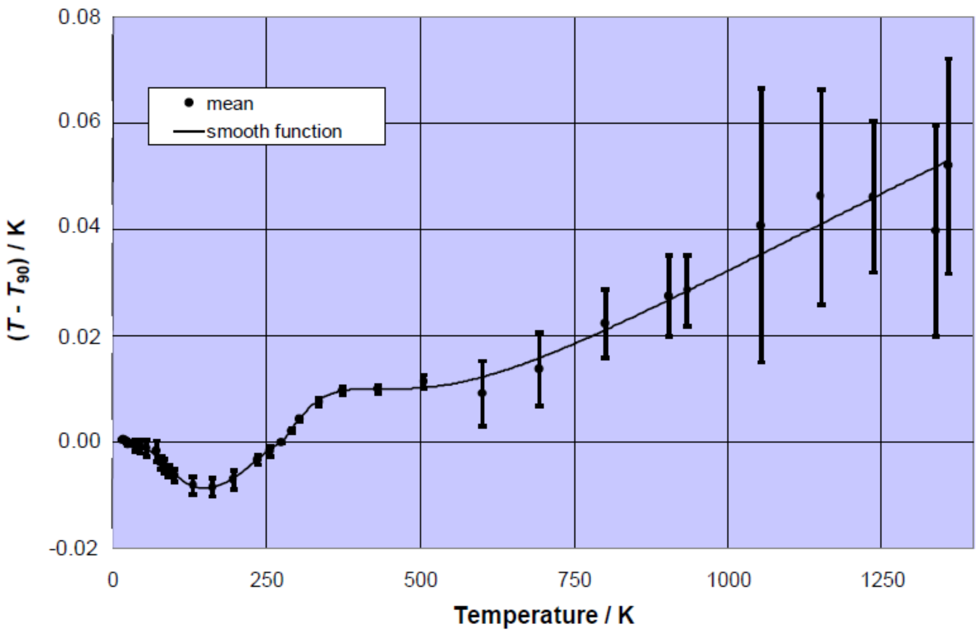

Figure 1 — Overview of consensus estimates for $T - T_{90}$ with emphasis on the range above the triple point of water. The smooth functions (Equation (1) and Equation (2), black line) are interpolating the mean values (black dots). Error bars represent uncertainties with $k = 1$.

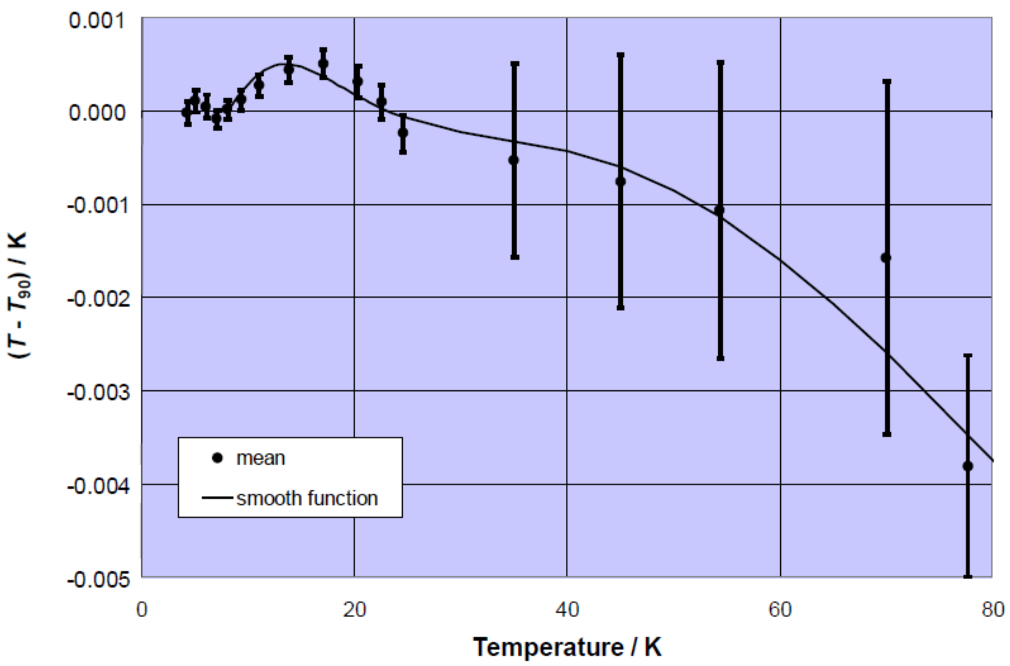

Figure 2 — Enlargement of the range between 4.2K and 80K of consensus estimates for $T - T_{90}$. The smooth function (Equation (1), black line) interpolates the mean values (black dots) above 8K. Error bars represent uncertainties with $k = 1$.

References

[1]] J. Fischer, M. de Podesta, K. D. Hill, M. Moldover, L. Pitre, R. Rusby, P. Steur, O. Tamura, R. White, L.Wolber, *Int. J. Thermophys.* **32**, 12-25 (2011).

[2]] J. Engert, B. Fellmuth, K. Jousten, *Metrologia* **44**, 40-52 (2007).

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