

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

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 4.2 K to 1358 K, as well as a recommendation for analytic approximations to $T - T_{90}$ for the range 0.65 K to 1358 K.

Table of Differences

Table 1 summarizes the best estimates of $T - T_{90}$ above 4.2 K 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 figures 1 and 2.

Table 1 Estimates of $T - T_{90}$ between 4.2 K and 1358 K. The transitions of the defining fixed points and 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 1358 K are under investigation by Working Group 5. The results presented here may be extrapolated above 1358 K 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 ₂ O	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

Interpolation Functions

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

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

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

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

From 2 K to 8 K,

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

From 8 K to 273.16 K,

$$(T-T_{90}) / \text{mK} = \sum_{i=0..7} b_i \times (\log_{10}(T_{90}/273.16 \text{ K}))^{i+1} \quad (1)$$

with the coefficients :

$$\begin{array}{llll} b_0 = 4.42457 \times 10^1 & b_1 = -1.76311 \times 10^2 & b_2 = -1.53985 \times 10^3 & b_3 = -3.63685 \times 10^3 \\ b_4 = -4.19898 \times 10^3 & b_5 = -2.61319 \times 10^3 & b_6 = -8.41922 \times 10^2 & b_7 = -1.10322 \times 10^2 \end{array}$$

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

From 273.16 K to 1357.77 K (copper point):

$$(T-T_{90}) / \text{mK} = (T_{90}/\text{K}) \sum_{i=0..4} c_i \times (273.16 \text{ K} / T_{90})^{2i} \quad (2)$$

with the coefficients:

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

The derivative at the triple point of water is 10.1×10^{-5} , resulting in a discontinuity of 3.1×10^{-5} between Eqs. 1 and 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.

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).

Figures

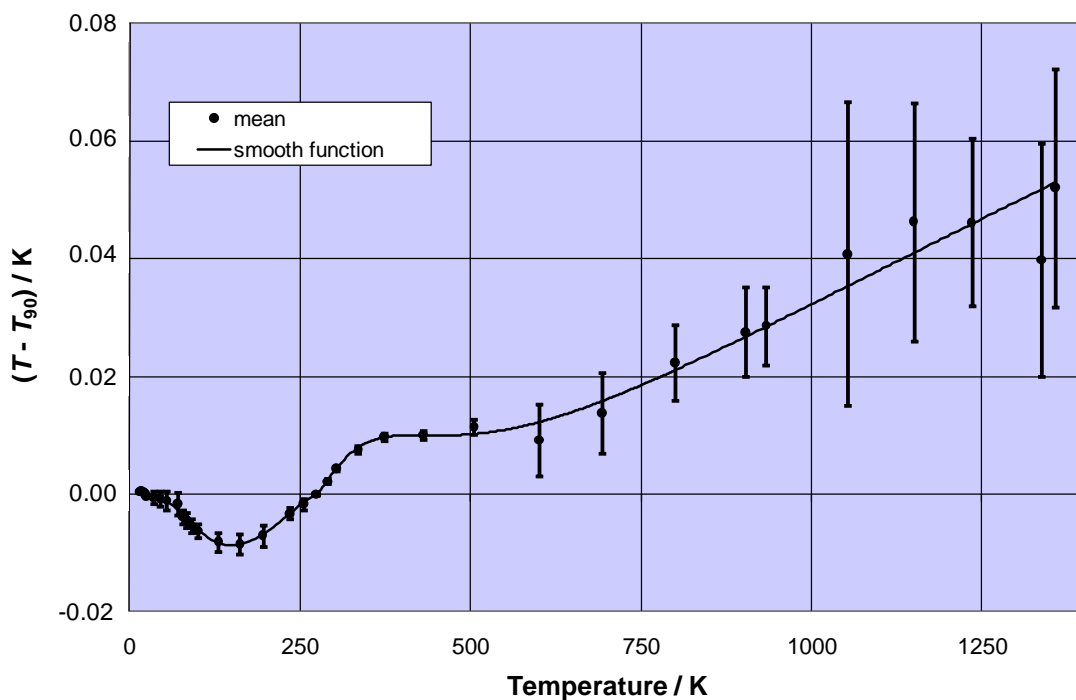


Fig. 1 Overview of consensus estimates for $T-T_{90}$ with emphasis on the range above the triple point of water. The smooth functions (Eqs. 1 and 2, black line) are interpolating the mean values (black dots). Error bars represent uncertainties with $k = 1$.

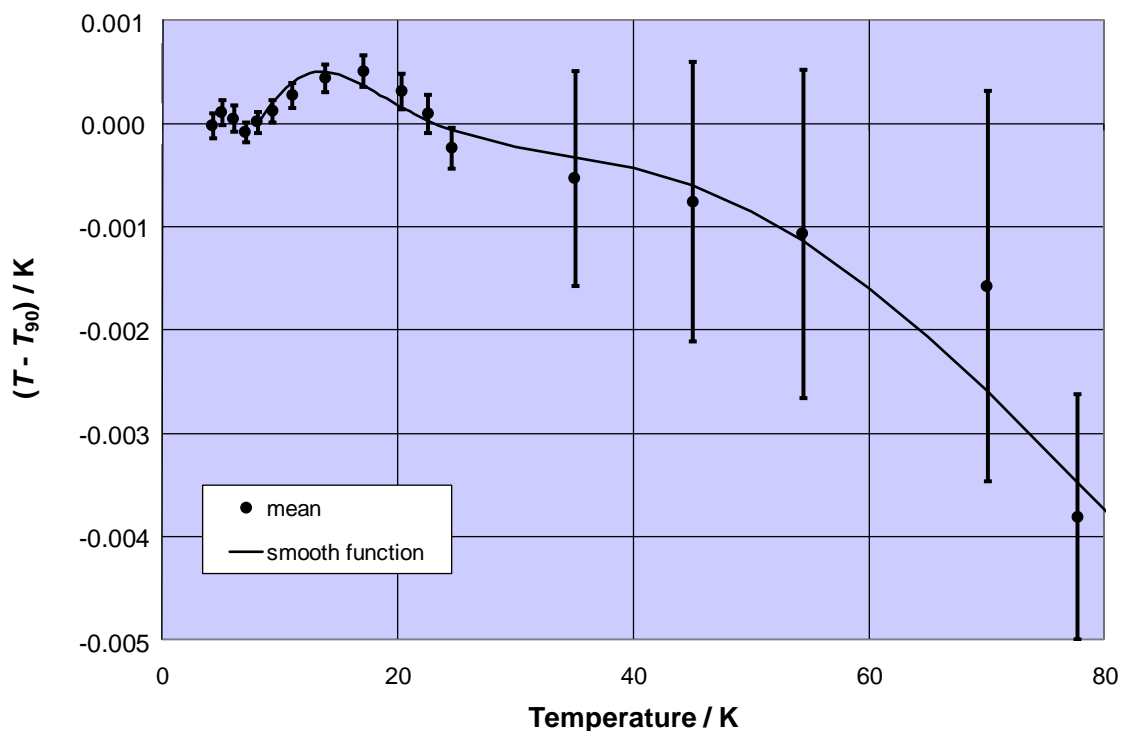


Fig. 2 Enlargement of the range between 4.2 K and 80 K of consensus estimates for $T-T_{90}$. The smooth function (Eq. 1, black line) interpolates the mean values (black dots) above 8 K. Error bars represent uncertainties with $k = 1$.