Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

“Highlights of the WG-CTh since 2024“

WG-CTh - Members

WG-CTh:

Chairperson:
Christof Gaiser (PTB)

Members:
Robin Underwood (NPL)
Jonathan Pearce (NPL)
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Vladimir Gennadiy Kytin (VNIIFTRI)
Hideki Ogura (NMIJ/AIST) substitutes Tohru Nakano (NMIJ/AIST)
Laurent Pitre (LNE-Cnam)
Anatolii Pokhodun (VNIIM)
Patrick Rourke (NRC)
Weston Tew (NIST)
Inseok Yang (KRISS)
Xiaojuan Feng (NIM)

Co-opted members:
Richard Rusby (NPL)
Bernd Fellmuth (PTB)
Peter Steur (INRIM)
Rod White

Terms of references of WG-CTh

I. reviewing and reporting on measurements of $T - T_{90}$ and $T - T_{2000}$

II. recommending key comparisons in contact thermometry to the CCT

III. reviewing the research and application of primary contact thermometers to realize the kelvin

IV. updating the Mise en Pratique of the definition of the kelvin

V. updating the Guides to the Realization of the ITS-90 and the PLTS-2000

VI. reviewing novel contact thermometry techniques

Activities since 2024

I. reviewing and reporting on measurements of $T - T_{90}$ and $T - T_{2000}$

DCGT
25 K, 70 K to 100 K

AGT 77 K to 303 K

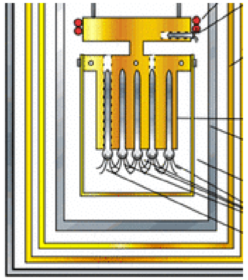
AGT13.8 K to 161 K

RIGT 25 K to 83 K

AGT 90 K to 303 K

AGT 25 K to TPW

AGT 173 K to 303 K



T comparison nearly completed

University of Ljubljana

First comparison of thermodynamic temperature in the range 4 K to 303 K using three methods (AGT, DCGT, RIGT)

DIREK-T

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Activities since 2024

I. reviewing and reporting on measurements of $T - T_{90}$ and $T - T_{2000}$

new high temperature AGT developed at 4 labs up to 700 K or 1300 K

Recommendation 1 of the 29th CCT (2021)

Requirement for new determinations of thermodynamic temperature above 400 K

The Consultative Committee for Thermometry (CCT), at its 29th meeting in 2020/2021,

DIREK-T

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Activities since 2024

I. reviewing and reporting on measurements of $T - T_{90}$ and $T - T_{2000}$

Differences Between Thermodynamic Temperature and ITS-90 Below 4.2 K

B. Fellmuth ; C. Gaiser

Check for updates

J. Phys. Chem. Ref. Data 54, 013102 (2025)
https://doi.org/10.1063/5.0252532

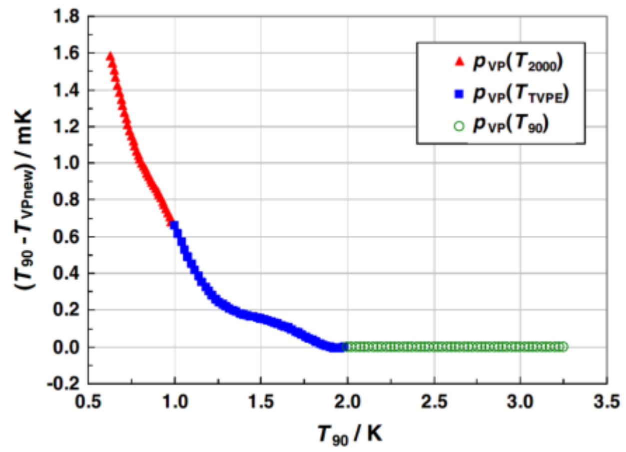

FIG. 3. Temperature differences between ITS-90 and PTB-2006. (Fig. 3 in Ref. 4 Differences at PTB between the helium-3 vapor-pressure equation of the ITS-90 and the input data set T_{VPnew} for the new helium-3 vapor-pressure scale PTB-2006 as a function of temperature. The three subgroup data sets for the new scale are marked by different symbols (VP stands for vapor pressure). For details, see Ref. 4.

TABLE 1. $(T - T_{90})$ data together with uncertainty estimates in the range 0.65–2 K. The $(T - T_{90})$ values have been calculated from the deviation between the polynomials for the helium-3 VPSs of PTB-2006 and ITS-90, respectively, exactly describable by a polynomial of similar form [Eq. (1)]. The $u(T - T_{90})$ estimates are based on a second-order polynomial fit function [Eq. (3)] of the estimates for the thermodynamic uncertainty of PTB-2006 given in Ref. 4.

T_{90}/K	$(T - T_{90})$/mK	$u(T - T_{90})$/mK
0.65	−1.53	0.43
0.70	−1.30	0.45
0.75	−1.13	0.47
0.80	−1.03	0.49
0.85	−0.94	0.51
0.90	−0.84	0.53
0.95	−0.74	0.54
1.00	−0.63	0.55
1.05	−0.53	0.57
1.10	−0.45	0.58
1.15	−0.38	0.59
1.20	−0.32	0.59
1.25	−0.27	0.60
1.30	−0.24	0.60
1.50	−0.14	0.60
2.00	−0.01	0.50

$$T - T_{90} / \mathrm{K} = \sum_{i=0}^{9} C_i \left[\alpha - \beta \ln \left(T / \mathrm{K} + \gamma \right) \right]^i$$

$$u(T - T_{90}) / \mathrm{mK} = \sum_{i=0}^{2} D_i (T / \mathrm{K})^i$$

II. recommending key comparisons in contact thermometry to the CCT

Different NMIs are working on alternatives to the mercury triple point (mainly CO_2 and SF_6) for an amended version of the ITS-90 or a new ITS-XX

Huge progress was made during the years, and it is very likely that a first key comparison will be recommended within the next years.

In addition, the comparison of primary thermometers performed within DireK-T is a precursor of a possible key comparison of thermodynamic temperature…

V. Updating the Guides to the Realization of the ITS-90 and the PLTS-2000

Proposed updates to “the Guide” have been discussed and a sub-group is working on the implementation.

Guide to the Realization of the ITS-90

Platinum Resistance Thermometry

A I Pokhodun, D I Mendeleyev Institute for Metrology, Russia
B Fellmuth, Physikalisch-Technische Bundesanstalt, Berlin, Germany
J V Pearce, National Physical Laboratory, Teddington, United Kingdom
R L Rusby, National Physical Laboratory, Teddington, United Kingdom
P P M Steur, Istituto Nazionale di Ricerca Metrologica, Torino, Italy
O Tamura, National Metrology Institute of Japan, AIST, Tsukuba, Japan
W L Tew, National Institute of Standards and Technology, Gaithersburg, USA
D R White, Measurement Standards Laboratory of New Zealand, Lower Hutt, New Zealand

A subgroup has worked on collation of new data for high-quality reference points. Work will be continued and supported by an invited expert in charge of Eutectics.

Update of WG2 article by Bedford and colleagues

metrologia

Recommended values of temperature on the International Temperature Scale of 1990 for a selected set of secondary reference points

R. E. Bedford, G. Bonnier, H. Maas and F. Pavese

Working Group 2 of the Comité Consultatif de Thermométrie

Abstract. Recommended values of temperature on the International Temperature Scale of 1990 are given for a large number of secondary reference points, together with assessments of the uncertainties of these values.

Review of Scientific Instruments REVIEW scitation.org/journal/rsi

High-accuracy realization of temperature fixed and reference points

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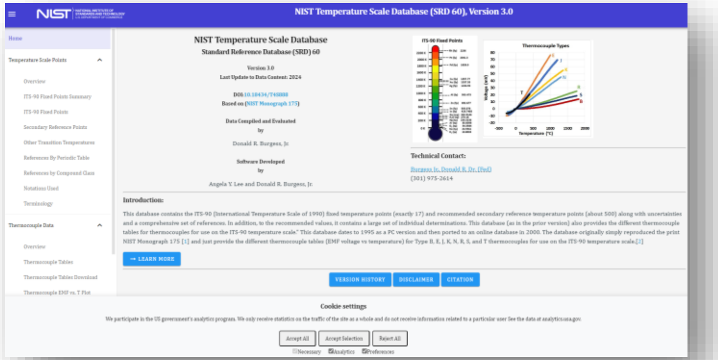
ABSTRACT

The harmonization of international temperature measurements requires the high-accuracy realization of many different temperature reference points. This results from the feature of the intensive measurand temperature that temperatures cannot simply be divided or multiplied. Thus, the points must cover the whole range of interest, at present from 1 mK to a few 1000 K. Furthermore, instruments are necessary for the interpolation between the non-continuous guide values. This led to the establishment of International Temperature Scales (ITS). The ITS prescribe interpolation instruments and assign fixed temperature values to suitable phase transitions without uncertainty. The large temperature range can only be covered by applying very different phase transitions. This includes the classical transitions, namely triple, melting, and freezing points, but also second-order transitions, as superfluid and superconducting ones, and the very new eutectic or peritectic points of metal-carbon compositions. A high-accuracy realization requires a reliable uncertainty estimation. This is, therefore, the central topic of this review. Since a given non-ideal condition of a sample, especially the impurity content, cannot be reproduced as accurate as necessary, the fixed- and reference-point temperatures are defined for ideal substances under ideal conditions. Thus, the estimation of the uncertainty of the realizations must be based on estimating the magnitude of all physical effects influencing the observed phase-transition temperature. The application of this methodology is discussed in the paper as unifying topic independent of the individual problems to be solved. Furthermore, recommendations of the *Consultative Committee for Thermometry* are summarized, and own experiences are supplemented.

NOMENCLATURE

Anisotropy effect (AE)	Decrease of the superconducting transition temperature in anisotropic superconductors due to smoothing out of anisotropy by the scattering effect of impurities
Cryogenic gases	Gases having boiling-point temperatures below 0 °C
GRT	Germanium resistance thermometer: One type from a variety of thermometers for low temperatures having a negative temperature coefficient (Rubin *et al.*, 1982)
Heat-flux correction	Correction of the depression of the lambda-transition temperature of helium-4 caused by a heat flux through the normal-fluid to super-



VI. Reviewing novel contact thermometry techniques

Photonic and Quantum Sensors for practical integrated primary Thermometry

PhoQuS-T

www.phoqus-t.com

The overall objective is to develop integrated optical practical primary thermometry from 4 K to 500 K to enable in-situ traceability in further practical applications. This will be reached through a combination of different technical approaches: with the optomechanical sensor, the quantum thermometry below 10 K will provide a quantum reference for the optical noise thermometry (operating in the range 4 K to 300 K), whilst using the high resolution photonic (ring-resonator) sensor the temperature range will be extended up to 500 K. The important issues of the robust packaging over the large temperature range will be addressed, as well as the metrological validation of the developed sensors and their future applications.

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VI. Reviewing novel contact thermometry techniques

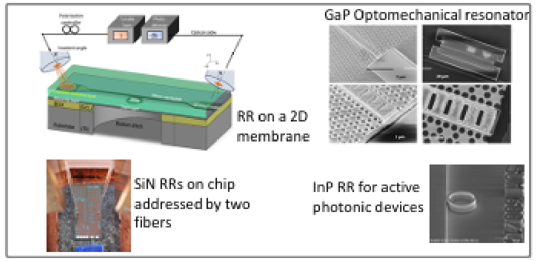
Towards Key Exploitable Results at M18 (Mid-Term)

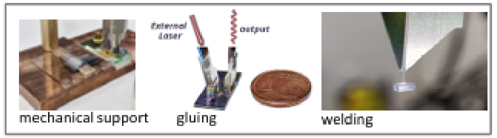
Key Exploitable Results

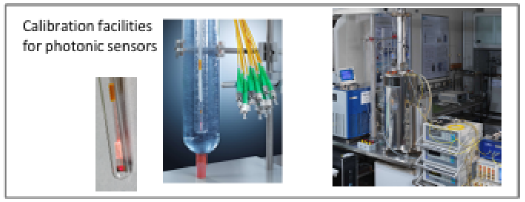
- ✓ **New device fabrication capabilities** for photonic ring resonators (RR), active photonic devices and optomechanical resonators important for embedded sensor technologies.
- ✓ **New sensor packaging capabilities** via laser welding, gluing or mechanical supports aiding implementation.
- ➢ **Special calibration facilities** traceable to ITS-90 for photonic and optomechanical sensors from 80 K to 500 K and 4 K to 300 K respectively, to facilitate implementation.
- ❑ **Demonstration of the self-calibration** of photonic techniques with a quantum reference.
- ❑ **Demonstration of the application** of the developed photonic sensor for quantum applications (ion-trap, pressure standard)

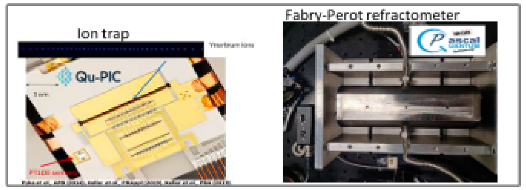
Progress :

- **New device fabrication capabilities developed.**
- **Tests started on dummy chips, first packages sample available.**
- **Under development by the involved NMIs.**
- **Not yet demonstrated, protocols are under development.**
- **Setups are ready for photonic sensors integration.**









VI. Reviewing novel contact thermometry techniques

INFOTherm

Fibre-optic thermometry can improve the measurement of temperature in extreme environments for energy providers and the industry sector due to distributed sensing and immunity to electromagnetic fields. The project aims to overcome the limitations that prevent the widespread use of fibre-optic thermometry by creating a dedicated European metrological infrastructure addressing research (e.g. measurement uncertainty), testing (e.g. industrial case studies), calibration (e.g. services and guides), and training (e.g. stakeholder workshop).

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Jonathan Pearce (Chair), Graham Machin – NPL

Maria-José Martín Hernández – CEM

Aleksandra Kowal – INTIBS

Åge Olsen – JV

Yijie Pan, Kunli Zhou – NIM

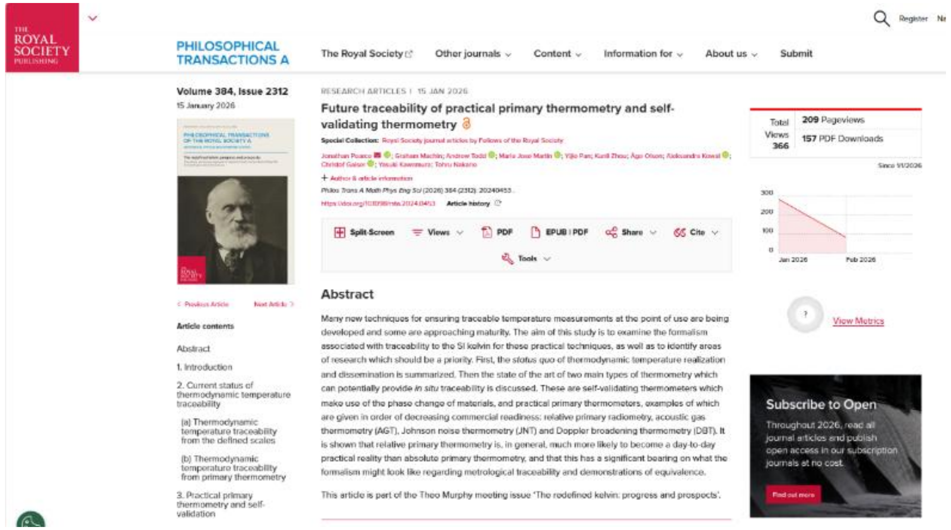
Yasuki Kawamura – NMIJ

Andrew Todd – NRC

Christof Gaiser – PTB

Aim until now

- Primary thermometry is now an important method and *T* is already being disseminated by some NMIs
- Practical primary thermometry techniques are being vigorously developed and are likely to be used ‘in the wild’ in the not-too-distant future
- *In-situ* traceability is being developed, mainly through self-validating thermometers
- The metrology framework needs to be formalised and the required developments targeted



Future aim

In the first part of the TG-TTT activities, four practical primary thermometry methods were evaluated, namely relative primary radiometric thermometry, acoustic gas thermometry, Johnson noise thermometry and Doppler broadening thermometry. The aim of the next phase is to: Select a wider set of methods in addition to the original four (e.g. magnetic field fluctuation thermometry)

- Survey the readiness of the selected techniques
- Map realistic traceability chains for each
- Establish performance benchmarks

Update of the CCT Strategy

Achievements 2021-2025	Future Scan 2025-2030+
Definition of the kelvin and *MeP*-K	
ITS-90 remains one of the key outputs of the CCT and the backbone of global traceable temperature measurement. Non-uniqueness studies have helped clarify the magnitude of this key uncertainty.	The operation of the MeP-K-19 to be reviewed by the CCT. The review should examine as a minimum whether ITS-90 and PLTS-2000 are still fit-for-purpose and continue to meet stakeholder needs (including examining cost of implementation and need), describe and agree how to incorporate thermodynamic temperature dissemination, and whether other thermodynamic temperature measurement approaches should be included.
Collation of an update low uncertainty of T-T90 data below 335 K has been performed and published.	CCT recommendation (T1 2021) "Requirement for new determinations of thermodynamic temperature above 400 K" is still current and these values are urgently required to help inform the deliberations about future temperature dissemination routes.
Demonstration and establishment of traceability directly to the redefined kelvin from ~1300 K to ~3000 K via low uncertainty thermodynamic temperatures of four new HTFPs (WC-C, Ru-C, Pd-C and Fe-C). New values HTFP Fe-C, Pd-C, Ru-C and WC-C. This completes the HTFP additions to the MeP-K annex in May 2024.	Launch new collaborative project, through a new task Group, in WG-NCTh about realising and disseminating the kelvin by primary thermometry in the temperature range above 505 K to 1235 K: primary thermometry capability by non-contact thermometry (especially by relative primary radiometry) between 505 K (tin freezing point) to 1235 K (silver fixed point). Link to parallel TG in CCT WG CT in high temperature acoustic gas thermometry for temperatures above 303 K (gallium fixed point) with the target of up to 700 K. The objective is to obtain coherent weighted values for $T-T_{90}$ and T, including full uncertainty characterisation.
The redefinition of the kelvin has stimulated research into practical primary approaches to establish traceability at the point of measurement; the most advanced of these are Johnson Noise Thermometry (JNT), Doppler Broadening Thermometry (DBT) and Ring Resonator Thermometry (RRT) – but there are others approaches.	Research into these more novel practical primary thermometry approaches – in principle capable of providing in-situ traceability – will continue in the second half of this decade. By 2030 it will be clear how successful these approaches might be, but it is likely that the JNT, DBT and RRT (or variant) will all have been demonstrated at a high TRL.

Actions from the last CCT meeting

17. Actions and decisions

Actions

The following actions are to be undertaken:

CCT31/A4: WG-CTh and WG-NCTh to present to the next CCT meeting an analysis on the conditions for a future update of the ITS-90.

Proposed recommendation to the CIPM

Criteria for the establishment of a new International Temperature Scale

recommends

- that CIPM ensures that there are new low-uncertainty evaluations of thermodynamic temperature above 400 K to bring T and any future T_{ITS} closer together fulfilling requirements concerning uncertainty, namely
  - the thermodynamic data should not be uncertain by more than a factor of two of the total uncertainty of the realization of the ITS-90 up to the freezing point of silver and
  - ensuring the reliability of primary thermometry (*i.e.* the data be based on at least two fundamentally different primary thermometry methods within the *MeP*-K, where at least one result for each should have a standard uncertainty not more than a factor of three of the total uncertainty of the realization of the ITS-90),
- that CIPM consult with key stakeholders so that a proper consideration of the cost of the introduction, implementation, and requirements of a new ITS be evaluated (*i.e.* a cost-benefit analysis be performed),
- that member state NMIs and DIs stimulate research
  - to solve the PLTS-2000 problem below 8 mK so that it could be considered for incorporation into a possible future ITS,
  - to improve the operating performance of high-temperature platinum resistance thermometers (where possible working with manufacturers) and
  - to demonstrate one or more viable alternatives to the triple point of mercury for the calibration of both capsule and long-stem platinum resistance thermometers,
- that, after the above items have been achieved, CCT perform a survey checking if primary thermometry is still only possible in very few NMIs and, therefore, not a practical way of realizing and disseminating thermodynamic temperature (which would justify a possible new ITS).

Proposed recommendation to the CIPM

recommends

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    - the thermodynamic data should not be uncertain by more than a factor of two of the total uncertainty of the realization of the ITS-90 up to the freezing point of silver and
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Proposed recommendation to the CIPM

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- that CIPM consult with key stakeholders so that a proper consideration of the cost of the introduction, implementation, and requirements of a new ITS be evaluated (*i.e.* a cost-benefit analysis be performed),
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Proposed recommendation to the CIPM

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- that, after the above items have been achieved, CCT perform a survey checking if primary thermometry is still only possible in very few NMIs and, therefore, not a practical way of realizing and disseminating thermodynamic temperature (which would justify a possible new ITS).

Thanks to all the members of WG-CTh

and CCT-TG-CTh-TTT

and thank you for your attention!