Welcome to the Newsletter of Real-K!

Welcome to the fourth Newsletter of Real-K. The research in Real-K is reaching a conclusion and striking results have been obtained in all the work packages. Significant highlights are reported in this newsletter, and I hope you enjoy reading about them here.

As the world has opened-up after the COVID-19 pandemic I want to highlight two very significant events that will take place in April.

Firstly, there is the 10th International Temperature Symposium **https://its10.msc-conf.com/** which will take place 3-7 April 2023 in Anaheim, California, USA. This decennial event, which is the most important for the global thermometry community, is the opportunity to take stock of the current state of thermometry research and practice around the world and to discuss future activities for the coming decade. The Real-K consortium is very well represented at the conference. The coordinator is giving the opening plenary address “Progress with Realising the Redefined Kelvin” which will, in part, showcase some of the excellent results obtained in the Real-K project. There is also a focused conference session dedicated to the results of the Real-K project. Here the work-package leaders will report on research highlights in areas as diverse as high and low temperature primary thermometry, ITS-90 life extension work in, for example, alternative fixed points and research towards making gas based primary thermometry more accessible and practical. In all the outcomes of the Real-K project will, make a very significant impact to the global thermometry community contributing at least 20 papers to the conference, which makes it the biggest single contributor to the event.

Then secondly, there is the important Euramet TC-T Technical workshop “Realising the redefined kelvin: Turning the *MeP-K* into reality”. This will be held on 19th April 2023 in Bratislava, Slovakia. This workshop will report on the findings of the Real-K project to the assembled Euramet TC-T contact persons from across the Euramet region. In addition, it will be open to attendees from all over the world, including through hybrid means. Besides presenting the results of the Real-K project the workshop will provide opportunity for the Euramet TC-T community through a facilitated discussion forum to give commentary on the functioning of the MeP-K-19 and informed review of the CCT Strategy 2020-2031. It is anticipated that this workshop will provide valuable input into the next revision of the MeP-K-19 and feedback to the CCT (when it meets in 2024) on whether the CCT Strategy is broadly still valid or requires revision.

The closing meeting of the Real-K project will be held on 18th April 2023 also in Bratislava, Slovakia. This will be a final opportunity for the consortium to meet and celebrate our achievements together. Thereafter in May and June the final reporting will be concluded.

Finally, as coordinator of the Real-K project, I want to thank my colleagues for the hard work and dedication they have shown. We have achieved much in the research that has been undertaken, advancing, on a broad front, the state of the art of thermometry in so many areas. It has been a privilege to lead such a dedicated group of researchers at this important juncture of the kelvin redefinition. However Real-K is not the end! I am delighted to announce that there is a follow-on project, part funded by the European Partnership in Metrology. This new project “Dissemination of the Redefined Kelvin” (DireK-T) will build directly on the achievements of Real-K work-package 4 (Facilitating full range primary thermometry) and take advantage of

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the time afforded by the ITS-90 life extension activities of Real-K work-package 3 to explore ways in which thermodynamic temperature can be robustly disseminated to users in the temperature range from 4 K to 300 K, and build primary thermometry capability for dissemination of thermodynamic temperatures up to 700 K. DireK-T will run from September 2023 until August 2026 and will be coordinated by the Italian National metrology institute INRIM. I look forward to working with colleagues in the DireK-T consortium to continue to advance the state of the art of primary thermometry in the coming years.

Professor Graham Machin FREng

Real-K Project Coordinator

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Research highlights

WP1: Realisation and dissemination of the redefined kelvin above 1300 K

In the last year of this project, the main remaining activities of the workpackage devoted to high-temperatures concerned the determination of the thermodynamic temperature of the phase transitions of the high-temperature fixed points developed in this project.

Indeed, a large number of cells (30+) were produced by the partners of the project during the early stages of this work following the hybrid design of cells (see fig.1).

The results of the thermal effect characterisation were necessary to include an uncertainty on this effect in the final uncertainty on the thermodynamic temperature assignment process

After their characterisation, the cells were sent to four different labs to perform their comparison and selection. The idea here is to select the best two cells of each point (Fe-C, Pd-C, Ru-C and WC-C) to circulate them for the independent determination of their thermodynamic temperatures.

Six partners have reported their thermdynamic temperature determination of the cells and derived the phase transition temperature by correcting the results for emissivity (going from radiance temperature to the radiating surface temperature) and temperature drop (correcting for the temperature gradient in the graphite wall between the melting material and the radiating graphite wall).

The agreement between the participants to this collective thermodynamic temperature assignment exercise was noticeably good (as can be seen in fig.3 for the WC-C point for example). This shows the maturity of thermodynamic temperature measurements techniques both for direct radiometric measurement (using radiometers of absolutely-calibrated radiation thermometers) and for relative thermodynamic temperature measurements (using high-temperature fixed points or ITS-90 fixed points with assigned thermodynamic temperaures).

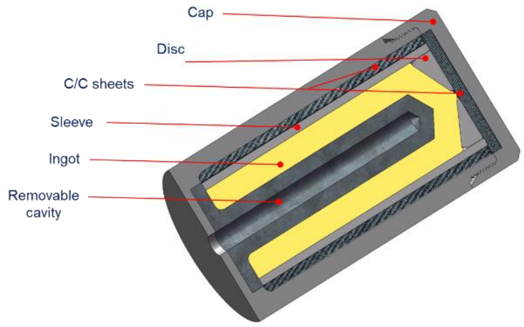

Fig.1 – Example of hybrid-design cell adopted during this project (series 7 of LNE-Cnam's design). Cell dimensions were 24 mm in diameter, 40 mm length and cavity opening of 3 mm.

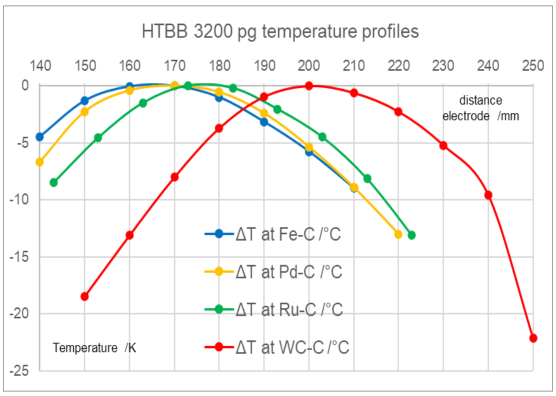

Fig.2 – Temperature profiles of a high-temperature blackbody furnace at the temperatures of the HTPFs under study. The profile was obtained by measuring the

It also shows that HTFPs can be considered as a convenient means for comparisons and for dissemination of the unit at high temperature.

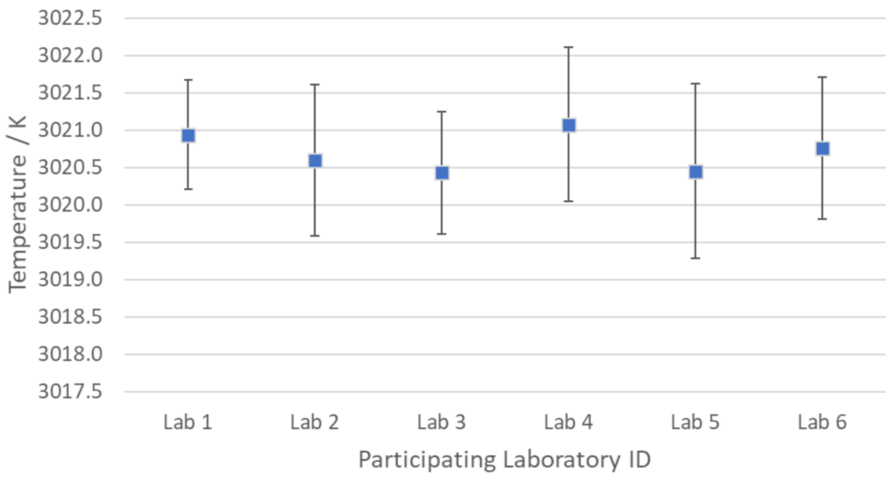

Fig. 3 – Reported thermodynamic temperatures for the WC-C phase transition with expended uncertainties (k=2).

The last steps of this work will be the comparison of the cells after their circulation to derive and correct their drift, if any. When this information will be known a definitive phase transition thermodynamic temperature will be calculated and published to complement the set of 3 HTFPs of assigned thermodynamic temperature already available, namely Co-C ~1597 K, Pt-C ~2011 K and Re-C ~2747 K (+ Cu ~1358 K) with a set of four new high-temperature fixed points: Fe-C ~1426 K, Pd-C ~1765 K, Ru-C ~2227 K and WC-C ~3021 K. This set of points would constitute a thermodynamic temperature scale among which any NMI can realise and disseminate thermodynamic temperature by interpolation over the most-suited temperature range.

WP2: Fixed and reference points for thermometer validation in the temperature range from 1 K to 25 K

After extending the working range of the primary magnetic field fluctuation thermometer (pMFFT) and the Coulomb blockade thermometer (CBT) to temperatures above 1 K and setting-up the fast acoustic gas thermometer (fast-AGT) for temperatures below 25 K, checks and characterizations of the primary thermometers have been carried out at highly stable and well characterized reference points. For the fast-AGT, the triple point of neon was chosen for the tests at LNE-Cnam, resulting in a thermodynamic temperature of 24.55515(24) K by applying the conventional AGT method [1].

For the pMFFT and the CBT, the transition of liquid ^{4}He from normal to superfluid state (λ-transition) has been used for the comparison at PTB, the temperature of which, in terms of ITS-90, is T_λ = 2.1768 K at saturated vapour pressure. Experimentally, a λ-point cell was used, which can maintain the λ-transition for many hours with microkelvin stability [2]. The λ-point cell was operated in a dry dilution refrigerator, and the thermometers under test can be directly mounted to the cell.

[1] Changzhao Pan et al, *Metrologia* **58**, 045006 (2021)

[2] J. Engert et al, *VDI Berichte* **1784**, 37 (2003), ISBN 978-3-18-091784-9

Fig 4 depicts the main results for the comparison between the pMFFT and the λ-point cell, the temperature of which was also monitored by a rhodium iron resistance thermometer (RIRT), which carries a copy of the ITS-90. The mean deviation between this ITS-90 copy and T_{λ} for 10 realizations of the λ-transition is –0.24 mK, corresponding to a mean relative deviation of -1.1×10^{-4}, while relative deviations of less than 0.2 % were observed for the pMFFT.

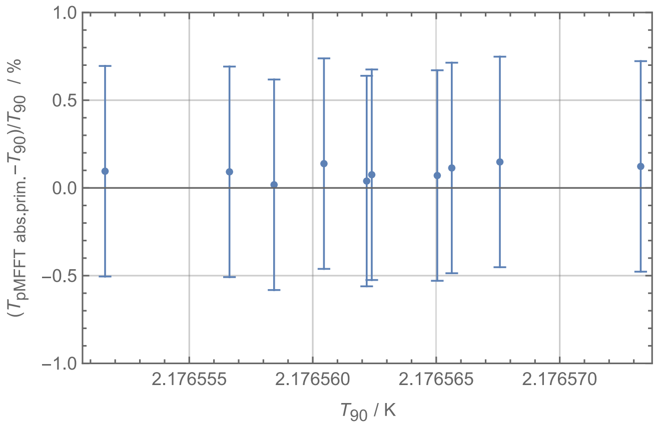

Figure 4. Relative temperature differences between a pMFFT operated in absolute primary mode and ITS-90 temperatures, T_{90}, for several independent realizations of the λ-transition.

WP3: Successful determination of Type 3 non-uniqueness with unprecedented precision

One key contribution to the uncertainty of standard platinum resistance thermometers (SPRTs), and hence the realization of the ITS-90, is Type 3 non-uniqueness, which arises from the difference between individual SPRTs over the same sub-range because of the differences in their resistance characteristics. Here there is a paucity of reliable data, particularly between −189 °C and 156 °C.

NPL, CEM and INTiBS have performed comparison measurements on cohorts of up to ten long-stem SPRTs of different manufacture and design. Each cohort comprised at least six locally maintained SPRTs, with two SPRTs which were circulated amongst the participants, to provide linkage between the three local investigations.

The NPL comparisons were carried out in a stirred silicone oil bath at ten temperatures between -95 °C and 20 °C, coupled with measurements at the TP Ar, -189.3331 °C. Similar comparisons were made at CEM at 18 temperatures between 0 °C and 80 °C, coupled with measurements at the freezing point of In (FP In, 156.5985 °C). Finally, comparisons were carried out at INTiBS between -189 °C and 0 °C, coupled with measurements at TP Ar and TP Hg.

By making the comparisons using ratios R_x / R_{ref}, where R_{ref} is the resistance of an SPRT chosen as the reference, and the R_x (x = 2 to n) are the resistances of the other n SPRTs, the resistances, and hence the ratios $W(T) = R(T) / R(0.01\ °C)$, and the differences (deviations) $W(T) - W_{ref}(T)$, can all be calculated. These deviations from $W_{ref}(T)$ can now be compared with deviations interpolated using the relevant equations (or the equivalent Lagrange functions) and the deviations at the chosen fixed points.

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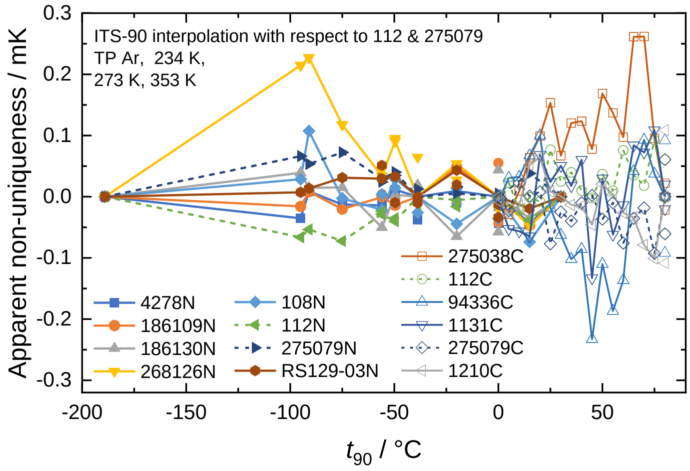

Fig 5: Apparent Type 3 non-uniqueness as a function of temperature: combined results of NPL (from TP Ar to -189 °C) and CEM (from 0 °C to 80 °C).

In Fig 5 the NPL results for the differences between the SPRTs (the apparent non-uniqueness) are merged with those of CEM, both with the baseline of the mean of the two common SPRTs, 112 and 275079. As these two SPRTs agree well with each other, the two sets of results are simply plotted together. 'N' against the SPRT serial number refers to NPL, 'C' to CEM. The differences measured at INTiBS between -189 °C and 0 °C are unfortunately too large to associate with SPRT non-uniqueness and it seems likely that they are due to systematic but quite repeatable temperature gradients between the SPRTs in the cryostat.

Few, if any, comparisons of long-stem SPRTs have been made so precisely, but the measurements reported here still only represent an upper limit, because, in addition to the Type 3 non-uniqueness, they incorporate experimental measurement uncertainty. However, they suggest that an assessment of the Type 3 non-uniqueness uncertainty need be no higher than ± 0.1 mK, at least between -95 °C and 30 °C, rising to ± 0.2 mK at 80 °C.

WP4: Facilitating full range primary thermometry

Among the main objectives of the Real-K project is the reduction the uncertainty of several primary thermometry methods, which are included in the *Mise en Pratique* for the definition of the kelvin, namely acoustic (AGT), dielectric constant (DCGT) and refractive index (RIGT) gas thermometry, and the extension the application range of these methods. These achievements will promote the development of simplified procedures for the direct dissemination of the thermodynamic temperature.

Theoretical ab initio calculation of thermometric gas properties

The improvement and simplification of primary thermometry methods requires the accurate knowledge of several thermophysical properties which enter in the corrections applied to account for the non-ideality of thermometric monatomic gases. For the sake of accurate AGT these properties include density- and acoustic virial coefficients as well as thermal conductivity. For thermometers based on the experimental determination of electromagnetic properties of gases, like DCGT and RIGT, accurate estimates of properties like electrical polarizability, magnetic susceptibility and dielectric virials are also needed. The substantial theoretical and computational effort implied by these

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requirements is being shared among the Real-K and the QuantumPascal EMPIR projects, with a focus of Real-K on the improved determination of thermodynamic and transport properties of He, Ne and Ar. Summarizing the progress achieved over the project duration, remarkably more accurate calculations of the interatomic two- and three-body potentials of He and Ne and, therefrom, of the thermodynamic and transport properties of the same gases, have become available. Particularly, the Quantum Chemistry Laboratory of the University of Warsaw (UW) has obtained and reported a five-fold reduction of the uncertainty of the calculated second virial coefficient $B(T)$ and the second acoustic virial coefficient $\beta_a(T)$ of He, based on a interaction potential which now includes relativistic and quantum-electrodynamic components, as well as the effects of the long-range retardation and of the nonadiabatic coupling of the nuclear and electronic motion. The same research group has recently completed a significantly improved calculation of the three-body potential of He. From this potential, in cooperation with the European Centre for Theoretical Studies in Nuclear Physics (ECT*) of the Bruno Kessler Foundation (FBK), the third virial coefficient $C(T)$ and the third acoustic virial coefficient $\gamma_a(T)$ of He could be determined with reduced uncertainty by respectively a factor of four and ten. The publication of these results is expected early in 2023.

Considering progress achieved in the ab initio calculation of the interaction potentials and the properties of Ne, new interatomic potential energy and interaction-induced polarizability curves for two ground-state Ne atoms were developed, and published, in 2021 by the Helmut Schmidt Universität (HSU), and used to predict the second density, acoustic, and dielectric virial coefficients and the dilute gas shear viscosity and thermal conductivity of Ne. More recently, relevant progress in the calculation of a non-additive three-body potential of Ne have been anticipated by the same group. From these improved potentials, improved density- and acoustic virial coefficients could be calculated up to 6th order using a semi-classical approximation. Also a fully quantum mechanical calculation of the 3rd virial coefficient of Ne was obtained by ECT*-FBK. Altogether these achievements will take the accuracy in the calculation of Ne properties beyond that which can be obtained by the most refined experiments, a possibility previously limited to He. As such Ne will be considered a reference substance for primary thermometry and other applications of fluid metrology.

In comparison to He and Ne, the progress obtained for the calculation of the potentials and properties of Ar has been less relevant, in reason of the computational challenges embedded in dealing with its more complex electronic structure. However, an improved three-body potential for Ar has been anticipated at an advanced stage of development by UW, though it is likely that it will be completed and published beyond the project lifetime.

Measurement and validation of thermodynamic properties of selected atomic systems

For the sake of validation of the theoretical progress illustrated above, a number of experimental measurements of thermodynamic properties of monatomic gases have been obtained and examined, in view of their consistency with theoretical predictions, during the lifetime of the Real-K project.

Highly accurate DCGT datasets measured at the Physikalisch-Technische Bundesanstalt (PTB) at temperatures from 24.5 K to 200 K were analyzed to obtain the difference between the second density and dielectric virial coefficients of Ne with previously unattained accuracy. Also, speed-of-sound measurements in Ne between 200 K and 420 K at pressures up to 100 MPa, were reported by the Helmut Schmidt Universität (HSU). In both cases, the agreement of the DCGT results of PTB and the speed of sound values of HSU with the calculations from new theory of Ne resulted to be very satisfactory (See Fig 6). To extend measurements to the range 100 K to 200 K up to 100 MPa, a new apparatus with LN_2 thermostat for speed-of-sound measurements has been completed by HSU. Together with the results of speed of sound measurements in argon in the range 120 K to 330 K previously obtained by NPL, the analysis of these sets of data will provide estimates of the acoustic virial coefficients of Ne and Ar which might support the accuracy of improved ab initio calculations of the same properties.

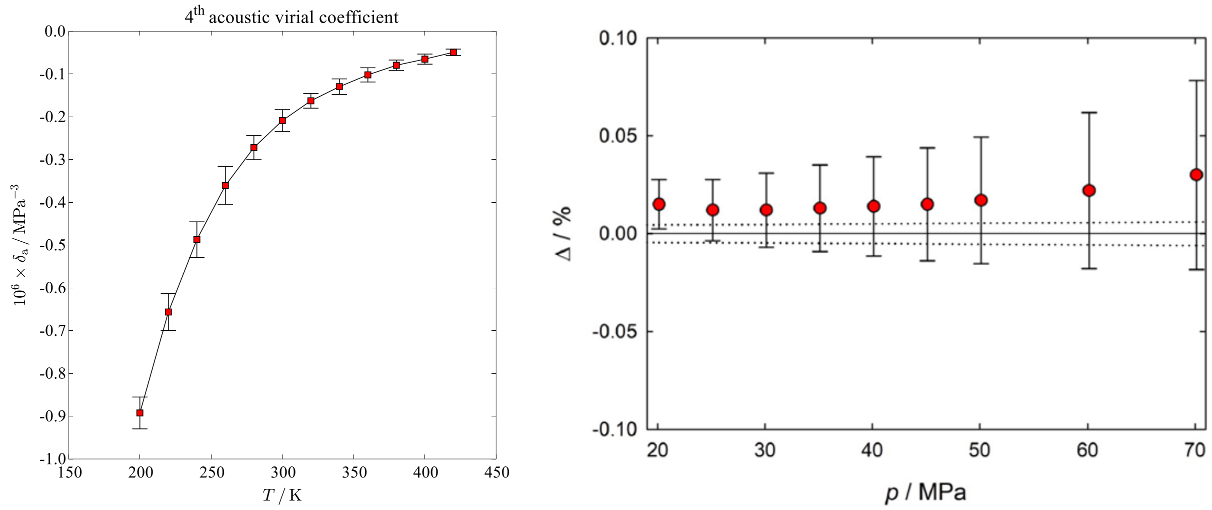

Fig. 6: (Left) Experimental determination of the 4th acoustic virial coefficients of Ne between 200 K and 420 K from speed of sound measurements at high pressure. (Right) Relative deviations of a virial equation of state of sixth order from speed of sound data in Ne at 420 K up to 70 MPa. The uncertainty bars and the dotted lines represent the uncertainty of theory and experiment respectively.

Coupled DCGT and Burnett expansion experiments with He, Ne and Ar were conducted at PTB in the temperature range between 253 K and 303 K. For He, measurements at 273.16 K and 296 K were completed allowing to determine the 2nd and 3rd density virial coefficients $B(T)$ and $C(T)$. The relative standard uncertainty of the 2nd virial $u_r(B)$ is lower than 1% and the results found consistent with the most recent theoretical estimates. Additional calibration measurements in He were used to constrain some experimental constants of the apparatus constant and to lower the uncertainties of Ne and Ar results. For Ar, measurements between 253 K and 303 K with relative standard uncertainties $u_r(B)$ = 0.5 % and $u_r(C)$ between 1.5 % and 3 % were obtained. Publication of these results is expected in 2023 together with a revised working equation to deduce the third density virial from the automated expansions.

Measurements of speed of sound in He using an AGT apparatus between 10 K and 273.16 K were obtained at Istituto Nazionale di Ricerca Metrologica (INRiM) aiming at accurate estimates of the 2nd and 3rd acoustic virial coefficients $\beta_a(T)$ and $\gamma_a(T)$. At 13.8 K the relative standard uncertainty of the 3rd acoustic virial $u_r(\gamma_a)$ spanned between 1% and 3% and found consistent with the most accurate estimate currently available. Acoustic results with were also analyzed between 10 K and 217 K to test the performance of the AGT primary thermometer. A RIGT version of the same cryogenic apparatus had been previously used at INRiM to determine the 2nd density virial of Ne in the temperature range between 54 K and 161 K. These determinations, published in 2021, compare favourably with the most accurate theoretical estimates published by HSU and additional measurements of the same property by PTB.

Implementing improved primary thermometry

A major objective of the Real-K project regards the simplification of two primary thermometry methods, namely DCGT and RIGT. It has been reported by PTB that a *commercial* version of DCGT, i.e. an apparatus based on commercially available instrumentation, has performed with absolute uncertainties within 7 mK when operated with Ar between 253 K and 303 K.

At INRiM, a RIGT primary thermometer was operated between 13.5 K and 161 K with an absolute uncertainty of 1.8 mK at 161 K. A second RIGT apparatus was used to determine the refractive index of He, Ne and Ar at 273.16 K, in the pressure range between 200 kPa and 1 MPa. Though the main objective of these measurements is to test the performance of a primary microwave pressure standard, the same data can be analyzed for thermometry when a calibrated pressure balance is used as a reference, with combined standard uncertainty below 5 mK.

Consolidation and report of improved primary thermometry

A revised update of the consensus estimate of the differences between the thermodynamic temperature T and its approximation (T_{90}), the temperature according to the International Temperature Scale of 1990, which includes several recent primary thermometry results obtained in the course of the Real-K project, has been completed and published by the working group on contact thermometry of the Consultative Committee for Thermometry (CCT). The new consensus estimate (see Fig. 7), with a significantly lower uncertainty compared to that published in 2011, provides an alternative to primary thermometry for those requiring accurate measurements of thermodynamic temperature.

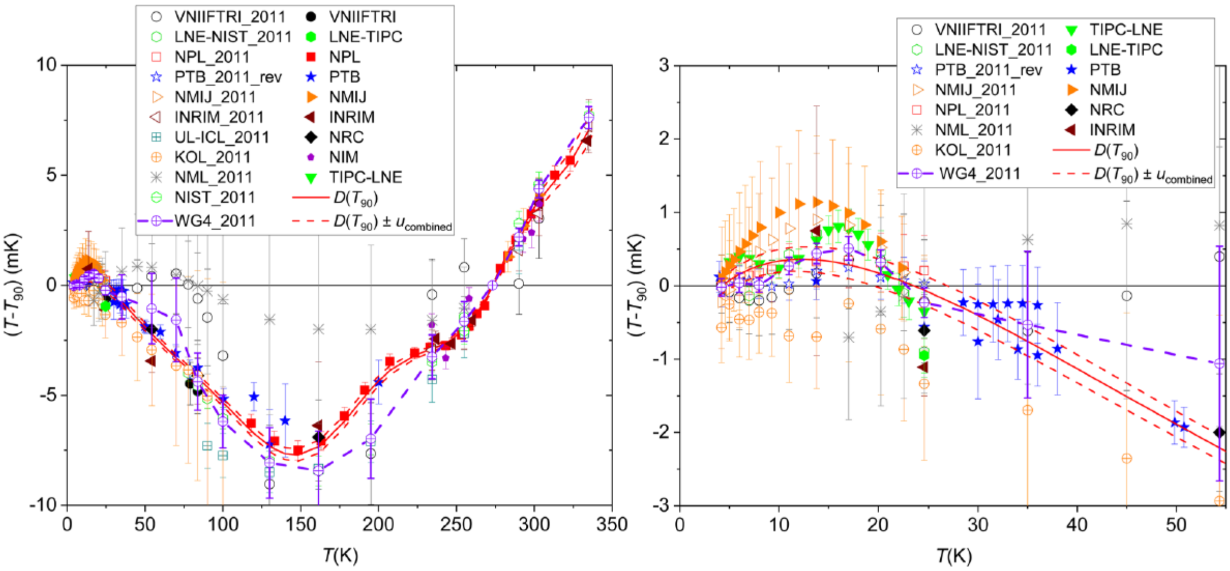

Fig. 7 – Differences ($T - T_{90}$) between thermodynamic temperature T and its approximation T_{90}. The red full line shows the interpolated fitting function D(T90), and the dashed lines envelop the range of its combined standard uncertainty (Right) Data and function display over the full scale range between 4.2 K and 335 K. (Right) Magnified data and function display over the range between 4.2 K and 55 K.

A review paper entitled ‘Ab initio calculation of fluid properties for precision metrology” is in preparation, discussing advances in high-accuracy electronic structure calculations, and how these results can be used to determine equations of state for pressure, speed of sound, dielectric constant, and refractive index of gases having metrological interest. The paper will be submitted to the Journal of Physical and Chemical Reference Data within the end of the Real-K project.

C. Gaiser, B. Fellmuth, R. M. Gavioso, M. Kalemci, V. Kytin, T. Nakano, A. Pokhodun, P. M. C. Rourke, R. Rusby, F. Sparasci, P. P. M. Steur, W. L. Tew, R. Underwood, R. White, I. Yang and J. Zhang “2022 Update for the Differences Between Thermodynamic Temperature and ITS-90 Below 335 K” *J. Phys. Chem. Ref. Data* **51** 043105 (2022)

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Dissemination of project results

Scientific articles

1. GAISER, Christof; FELLMUTH, Bernd; HAFT, Norbert. Thermodynamic-temperature data from 30 K to 200 K. *Metrologia*, 2020.
2. GAO, Bo, et al. Measurement of thermodynamic temperature between 5 K and 24.5 K with single-pressure refractive-index gas thermometry. *Metrologia*, 2020.
3. WANG, Yanfei, et al. A method for spectral irradiance measurement based on a large area WC-C fixed point blackbody. *Optics Express*, 2020, 28.19: 28430-28440.
4. PAN, Changzhao, et al. Active suppression of temperature oscillation from a pulse-tube cryocooler in a cryogen-free cryostat: Part 1. Simulation modeling from thermal response characteristics. *arXiv preprint arXiv:2002.03177*, 2020.
5. PAN, Changzhao, et al. Active suppression of temperature oscillation from a pulse-tube cryocooler in a cryogen-free cryostat: Part 2. Experimental realization. arXiv preprint arXiv:2002.03178, 2020.
6. IMBRAGUGLIO, Dario; STEUR, Petrus Paulus Maria; SPARASCI, Fernando. Comparison of ITS-90 realizations from 13 K to 273 K between LNE-CNAM and INRIM. Measurement, 2020, 166: 108225.
7. HAHTELA, O. M., et al. Coulomb Blockade Thermometry on a Wide Temperature Range. In: 2020 Conference on Precision Electromagnetic Measurements (CPEM). IEEE, 2020. p. 1-2.
8. G. Garberoglio and A. Harvey, Path-integral calculation of the fourth virial coefficient of helium isotopes, The Journal of Chemical Physics
9. A. Peruzzi, et al. Survey of Subrange Inconsistency of Long-Stem Standard Platinum Resistance Thermometers, Metrologia.
10. D. Madonna Ripa, at al. Refractive index gas thermometry between 13.8 K and 161.4 K, Metrologia.
11. P. Changzhao, *et al*. Acoustic measurement of the triple point of neon TNe and thermodynamic calibration of a transfer standard for accurate cryogenic thermometry, Metrologia.
12. Martín, M.J., Mantilla, *et al.* Construction, Characterization and Measurement of Fe–C and Pd–C HTFPs at CEM. *Int J Thermophys*43, 57 (2022).
13. Czachorowski P. , et al. Second virial coefficients for 4He and 3He from an accurate relativistic interaction potential. Phys. Rev. A 102, 042810 (2020).
14. Madonna Ripa D. et al. Corrigendum: Refractive index gas thermometry between 13.8 K and 161.4 K (2021 Metrologia 58 025008)
15. Pekola J. P.et al., Influence of device non-uniformities on the accuracy of Coulomb blockade thermometry, Metrologia
16. Machin G. et al., Towards realising the redefined kelvin, Measurement
17. Machin, G. (2023). The Kelvin Redefinition and Practical Primary Thermometry: Implications for temperature traceability and sensing. *Johnson Matthey Technology Review*, *67*(1), 77-84.

18. Can M., Gözönünde C., Arifoviç N, Yıldız F., and Nasibov H. (2023), “Large-area Fe–C Eutectic Fixed-Points for Radiation and Contact Thermometry”, Measurement Science Technology. Accepted, in publishing.

Presentations and other disseminations

1. Progress in Realising the Redefined Kelvin, Invited oral presentation at SMSI – Sensor and Measurement Science International 2021, May 2021
2. Towards realising the redefined kelvin, presentation at International Congress on Metrology (CIM 2021), Sep 2021
3. Coulomb Blockade Thermometry on a Wide Temperature Range, Aug 2020, IEEE Precision Electromagnetic Measurements (CPEM 2020), United States.
4. Construction of high temperature fixed points of Fe-C and Pd-C at CEM, poster presentation at CIM 2021, September 2021
5. New thermodynamic temperature references up to 3020 K, poster at CIM 2021, Sep 2021
6. Progress with realizing the redefined kelvin, presentation at ITS-10, APR 2023
7. Assigning thermodynamic temperatures to a set high-temperature fixed points in the range 1400 K to 3000 K, presentation at CIM 2023, MAR 2023
8. Realization of new fixed point cells at the LNE-Cnam, poster at CIM 2023, Mar 2023
9. Realizing the redefined kelvin: Extending the life of ITS-90, presentation at ITS-10
10. Investigations of Type 3 non-uniqueness in Standard Platinum Resistance Thermometers between 83 K and 353 K, presentation at ITS-10
11. Comparison of Different Johnson Noise Thermometers From Millikelvin Down to Microkelvin Temperatures, presentation at 29th International Conference on Low Temperature Physics (LT29), Aug 2022
12. Can M., Korkmaz M., Gözönünde C., Arifovic N., Nasibov H. (2023, March), “Realization of Fe-C Eutectic Point at UME”, 21th International Metrology Congress (CIM2023).
13. Can M., Nasibov H. (2023, February), A presentation “Development of new MC and MC-C fixed points for high-temperature metrology and the European joint project, Real-K, “Realizing the new kelvin,2019-2023)” for the academic staff of Physics and NanoTechnology Institutes of Gebze Technical University.
14. Can M., Korkmaz M., Gözönünde C., Nasibov H. (2023, April), “Realizing of Fe-C, Pd-C, Ru-C and WC-C eutectic fixed-points at UME”, 10th International Temperature Symposium (ITS-10).
15. Realising the redefined kelvin: Realisation and dissemination of the kelvin below 25 K, 10th International Temperature Symposium (ITS-10).

Forthcoming events

- 10th International Temperature Symposium https://its10.msc-conf.com will take place 3-7 April 2023 in Anaheim, California, USA.
- Euramet TC-T Technical workshop “Realising the redefined kelvin: Turning the *MeP-K* into reality” will be held on 19th April 2023 in Bratislava, Slovakia.

Consortium and contact information

The consortium consisting of national metrology, research institutes and universities brings together a critical mass of recognised world leaders in the field.

Project coordinator: Graham Machin (**graham.machin@npl.co.uk**).

Project website: https://real-k.aalto.fi.

Newsletter: Every nine months an e-Newsletter will be available via the project **website**.

Inquiries and more info, Contact Shahin Tabandeh (**shahin.tabandeh@vtt.fi**).

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