

Title: Disseminating the redefined kelvin at intermediate temperatures

Abstract

A metrology research infrastructure within Europe in the field of implementing, realising and disseminating the kelvin by primary thermometry was previously established to ensure that European temperature metrology infrastructure is world leading, integrated and able to meet current and future needs for industry, science and policy making. This infrastructure develops low uncertainty primary thermometry capability, performs thermodynamic temperature measurements for future thermodynamic temperature dissemination, and prepares for a possible future international temperature scale. Building on the established research capability in this area, proposals addressing this topic should aim to develop capability for future thermodynamic temperature traceability in the range from ~303 K to at least 1235 K.

Keywords

Thermometry, redefined kelvin, thermodynamic temperature, temperature dissemination, primary thermometry, redefined SI

Background to the Metrological Challenges

Since the kelvin redefinition in May 2019, temperature traceability has been regulated by the *mise en pratique* for the definition of the kelvin (*MeP-K*). The *MeP-K* allows for both defined temperature scales and prescribed thermodynamic thermometry approaches to be used to realise and disseminate temperature. The CIPM CCT issued a recommendation strongly encouraging "...member state NMIs take full advantage of the opportunities for the realisation and dissemination of thermodynamic temperature afforded by the kelvin redefinition and the *MeP-K*" [1]. Both the *MeP-K* and the recommendation were a recognition that realising and disseminating thermodynamic temperature instead of a defined scale has distinct advantages such as: a) providing direct linkage to the SI unit the kelvin (thermodynamic temperature) rather than by an intermediary defined scale, and b) the most appropriate thermodynamic temperature approach can be used at the temperatures required. Thus, the realisation and dissemination of thermodynamic temperature would essentially permanently futureproof temperature measurement. However, the step to achieve this is significant and has been the concentrated focus of research activity for the global thermometry community, led from Europe, since the SI redefinition. In Europe that activity has been centred on the EMPIR project 18SIB02 Real-K which started the transition to disseminating thermodynamic temperature for high temperatures above the freezing point of silver and low temperatures < 25 K, and on the Metrology Partnership project 22IEM02 DireK-T which has done much the same for temperatures to ~300 K. The pressing need now is to extend this work to the most challenging part of the temperature scale, namely intermediate temperatures above 300 K to 1235 K (that challenge is recognised by CCT/29 (2021) recommendation T1 "Requirement for new determinations of thermodynamic temperature above 400 K" [2]) and establish capability to benefit realising and disseminating thermodynamic temperature over the full temperature range.

The current state of the art regarding temperature traceability is the calibration of practical sensors to one of the defined scales the International Temperature Scale of 1990 (ITS-90) and the Provisional Low Temperature Scale of 200 (PLTS-2000). Through the work of the EMPIR project 18SIB02 Real-K traceability to thermodynamic temperature at high temperatures is set to become a reality in the next few years. In addition, traceability to thermodynamic temperature has become possible at lower temperatures below 5 K through Johnson Noise Thermometry. Finally, by the end of the Metrology Partnership project 22IEM02 DireK-T, the

possibility of traceability to thermodynamic temperatures to around 300 K will have been demonstrated, potentially opening the way to disseminate thermodynamic temperature to 300 K before 2030 as identified in the CCT Strategy [3]. However, for the temperature range above 300 K and below 1300 K thermodynamic methods are emergent rather than ready for providing traceability. The proposal should take important steps towards developing capability for providing such traceability by the end of the decade and provide important new reference $T-T_{90}$ values for the differences between the thermodynamic temperature, T , and the temperature defined by the ITS-90, T_{90} with documented uncertainties for any future temperature scale, if such is required.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The proposal shall focus on developing capability required for realising and disseminating thermodynamic temperature in the range above 300 K to at least 1235 K.

The specific objectives are

1. To establish primary thermometry capability by non-contact thermometry between 505 K (tin freezing point) to at least 1235 K (silver freezing point), with relative uncertainties below 10 ppm. In addition, to determine the difference between thermodynamic temperature and the ITS-90 (e.g., at the fixed-points of In, Zn, Al, Ag), and to explore potential dissemination routes for thermodynamic temperature.
2. To establish capability in high temperature acoustic gas thermometry for definitive determination of the difference between thermodynamic temperature and the ITS-90, and to explore potential dissemination routes for thermodynamic temperature. This includes a) developing acoustic resonators with relative uncertainties below 10 ppm for temperatures above 303 K with the target of up to 700 K, b) developing high-performance isothermal enclosures, and c) assembling measurement systems and solving key technical challenges, e.g., gas cleanliness, low-perturbation coupling of acoustic signals into the resonator, thermal expansion and material oxidation.
3. To achieve the world's lowest uncertainties for thermodynamic temperature by performing temperature measurements using the capabilities established in objective 1: relative primary radiometry over the temperature range from 505 K to 1235 K (potentially extending down to 430 K and up to 1358 K) and in objective 2: primary acoustic thermometry up to at least 505 K (with target of 700 K if facilities allow).
4. To synthesise the results of objective 3 into coherent weighted values for $T-T_{90}$ and T , including full uncertainty characterisation. This includes performing a quantitative comparison of the thermodynamic thermometry measurement capability for the different participants and indicating the feasibility of the approaches for provision of future temperature traceability. To ensure robust uncertainties by using the two independent thermodynamic thermometry approaches in temperature overlap region (505 K to 700 K).
5. To demonstrate the establishment of an integrated European metrology infrastructure and to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (calibration laboratories, NMIs), standards developing organisations (CIPM CCT) and end users (thermometry stakeholder community).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources both within and outside Europe, plus engagement with existing European research infrastructures and European Partnerships is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry and end users. Where relevant, proposals are encouraged to build on, or seek collaboration with, existing projects and develop synergies with other relevant European, national or regional initiatives and funding programmes. In particular, links are encouraged with (i) the projects funded under earlier relevant topics of the Horizon Europe programme; or (ii) other relevant European Partnerships.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMPIR project 18SIB02 Real-K and the Metrology Partnership project 22IEM02 DireK-T and how their proposal will build on those.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.1 M€ and has defined an upper limit of 2.6 M€ for this proposal.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 25 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the 'end user' community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g. letters of support) is also encouraged.

You should detail how your proposal's results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability, or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the thermometry sector.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)".

You should also detail how your approach to realising the objectives will further the aim of the Metrology Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Timescale

The project should be of up to 3 years duration.

Additional information

The links provided in this section are only correct at the time of publication up until the end of the Call year.

The references below were provided by PRT submitters; proposers should therefore establish the relevance of any references.

- [1] CIPM CCT: Recommendation 1 of the 28th CCT (2017)
<https://www.bipm.org/en/committees/cc/cct/28-2017/resolution-1>
- [2] CIPM CCT: Recommendation 1 of the 29th CCT (2021)
<https://www.bipm.org/en/committees/cc/cct/29-5-2021/resolution-1>
- [3] CIPM CCT: Strategy Document for Rolling Programme Development from 2021 to 2030
<https://www.bipm.org/documents/20126/41598583/CCT+Strategy/145827b2-4f6a-42ed-bd77-bbffa782e2f7>