Implementing the new kelvin 2 — 2nd Newsletter

Welcome to the 2nd Newsletter of InK2 project! We have been making good progress in developing world leading primary thermometry apparatus and sensors for the next stage of the project. Just a few selected highlights are (more details and highlights in the Newsletter):

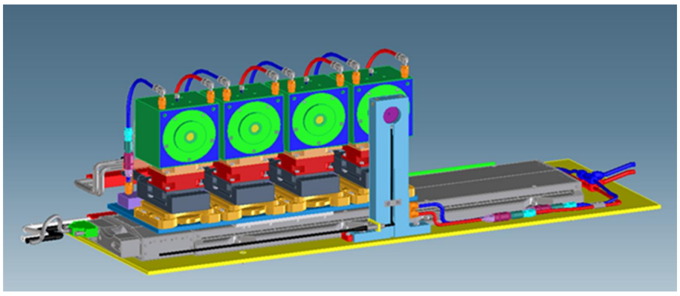
- the commissioning of the new dual pressure controlled heat pipe facility at NPL for radiometric measurements of $T–T_{90}$ to around 1300 K,
- development of refractive-index gas thermometry (RIGT) apparatus based on a microwave resonator by INRiM,
- novel thermometry experimental implementations for ultra-low temperature region: primary magnetic field fluctuation thermometer by PTB and Coulomb blockade thermometer by Aalto.

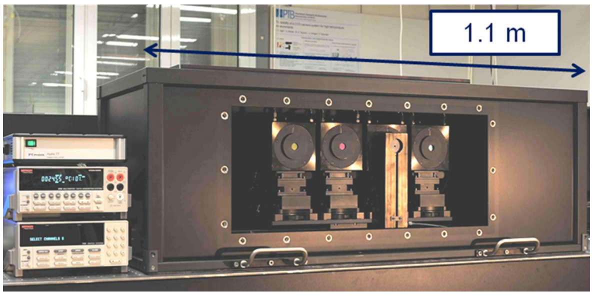
The ex-EU unfunded partners are making strong contributions. The Technical Institute of Physics and Chemistry (Chinese Academy of Sciences) is establishing a new primary thermometry laboratory for Refractive Index Thermometry on the outskirts of Beijing, the Chinese National Measurement Institute is developing high temperature acoustic gas thermometry capability and VNIIOFI in Russia is constructing novel large aperture high temperature fixed points for use at the synchrotron light source experiment.

All these developments should come together in the next stage of the project where measurements will be performed of $T–T_{90}$ and $T–T_{2000}$ in WP1, 2 and 4 from spring 2018 to early 2019. These will be combined into consensus values at a CCT workshop in May 2019 in Berlin. The results of the project will be presented to the wider scientific community in May 2019 at a Helmholtz Fonds workshop also in Berlin. This year we will hold our project meeting on the 7th September immediately after the IMEKO World Congress in Belfast, http://www.imeko2018.org/.

I hope you enjoy this Newsletter and reading of the progress in the InK2 project. Please feel free to pass it on to interested parties and if you know of people who may be interested in joining the Stakeholder community please let me myself or the editor of this Newsletter, Ossi Hahtela (ossi.hahtela/at/vtt.fi), know.

Prof. Graham Machin
InK2 coordinator





A four-wavelengths ratio filter radiometer (FRFR) developed at PTB for applying three primary radiometric standards (cryogenic radiometer, blackbody radiator and electron storage ring) with one instrument; see details in article.

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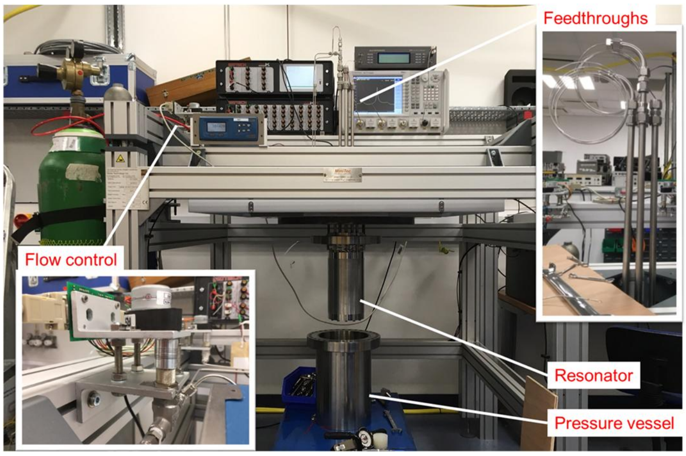
Research highlights

Dual pressure controlled heat pipe facility

NPL has measured their first full isotherms at 30 °C and 156 °C. This required the completion of the gas-handling system, which controls gas purity, flow rate and pressure. Also, the temperature stability and gradient control were improved.

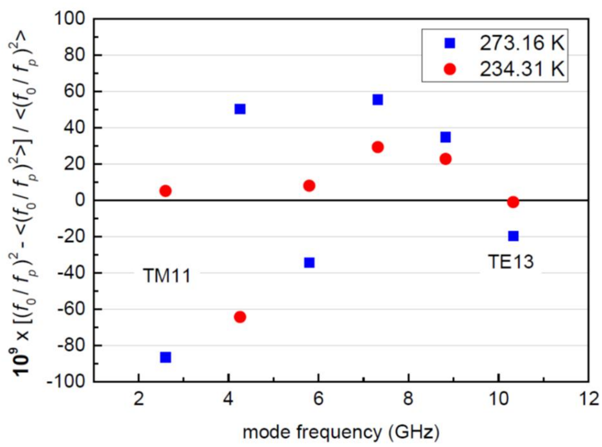


One of the key challenges in using cylindrical resonators rather than spherical resonators is getting agreement on the speed of sound from three different types of resonance: longitudinal modes, radial modes and hybrid modes. In longitudinal resonances, the sound waves travel end-to-end along the axis of the cylinder, but in radial resonances, the sound waves travel inwards and outwards along radii. The hybrid modes combine elements of longitudinal and radial modes. The corrections and shell coupling for each type of resonance are quite distinct and so the level of agreement between different modes is a measure of how well the physics of the resonator has been uncerstood. Experiments to verify the level of agreement were carried out at 156 °C. NPL is working to understand the origin of the variability in the data and to reduce the scatter to around 2 ppm.

Refractive-index gas thermometry (RIGT)

INRiM has completed the realization of a refractive-index gas thermometry apparatus based on a microwave resonator mounted within a pulse-tube cryostat. Initial tests of the cryostat performance demonstrated its operability within the temperature range between 32 K and ambient temperature. These tests evidenced vacuum/pressure leaks from the internal vessel hosting the resonator, thus preventing to fully achieve operating conditions. Needed modifications of the cryostat design are underway to solve these problems.

A new diamond-finished 0.5 litre ellipsoidal copper resonator has been delivered to INRiM and is currently being installed to the apparatus. Moreover, refractive index measurements were carried out in He and Ar at 234.31 K (triple point of Hg) and 273.16 K (triple point of water) for pressures up to 0.8 MPa using a copper cavity in a liquid-bath thermostat to estimate the uncertainty contribution of frequency measurements using different microwave modes over the frequency range from 2.5 GHz to 11 GHz, which resulted to be at the relative level of ±50 ppb (see figure).



Relative inconsistencies in ppb between squared frequency ratios (vacuum/0.8 MPa) from six microwave modes in a copper cavity at 273.16 K and 234.31 K.

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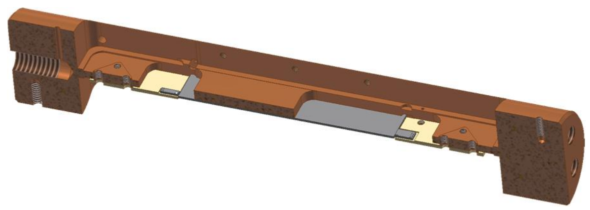
Novel thermometry experimental implementations for ultra-low temperature region

Primary magnetic field fluctuation thermometer

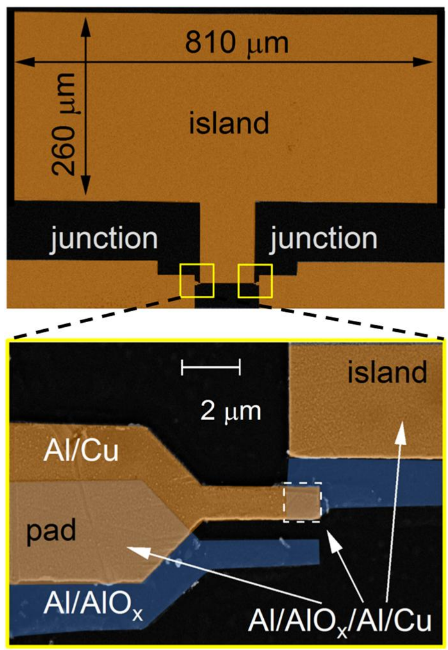
At PTB the limit of the cross-correlation readout of a SQUID-based low-temperature Johnson noise thermometer, specifically a primary magnetic field fluctuation thermometer (pMFFT), has been determined. In practice, the thermal noise signals from which the temperature is derived may be deteriorated by parasitic noise contributions caused by the environment and by the measurement electronics and the setup, provided there is a minor correlation. For the pMFFT, the cross-correlation readout reduces the influence of such unwanted noise contributions by a factor of about 100 000 in the temperature range below 1 K. The corresponding device noise temperature has been found to be as low as 2.5 µK, indicating that reliable measurements of thermodynamic temperature with the pMFFT are possible down to that limit which is about 400 times lower than the lower end of the International Temperature Scale PLTS-2000.



Left: Inside view of the standard pMFFT body (cut) with one Si chip (gray) and two SQUID-PCBs (light yellow) assembled. The noise sensor is the copper part above the left side of the Si chip. Right: Inside view of the setup with noise sensor removed for the cross-correlation limit measurements and Si chip (gray) and two SQUID-PCBs (light yellow) assembled.

Coulomb blockade thermometer

A new design and concept of Coulomb blockade thermometer (CBT) sensors has thoroughly been investigated at Aalto University, Finland. The number of the tunnel junctions was drastically reduced to two (see the figure at right) in order to minimize the parasitic heating to CBT sensors. This enables an enormous increase of the island size, improving thermalization accordingly. The electromagnetic environment of such sensors needs to be designed in such a way, that thermometry is not altered by its influence. This was achieved by designing a very low impedance of the connecting leads using capacitive shunting of the measurement leads to a ground plane. Simulations give solid and realistic design rules how to suppress the deviations of the sensor read-out due to the environment to the desired level of less than 0.1 %. Two sets of CBT sensors were fabricated and tested thoroughly at low temperatures down to 40 mK at Aalto University and down to 2.8 mK by the colleagues at University of Basel, Switzerland; see details in article.



A new design of the CBT with two tunnel junctions and a large Cu island for improving the thermalization.

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Al fixed points to be used as transfer standards

Three aluminium fixed points were constructed following the usual filling procedure of CNAM, the so-called "piston method" developed for the construction of high-temperature fixed points and applied to the filling of pure-metal fixed points of the international temperature scale (ITS-90). The cells were characterized in two newly commissioned furnaces by measuring the melt and freeze plateaus with different furnace temperature set points and different furnace temperature distributions.

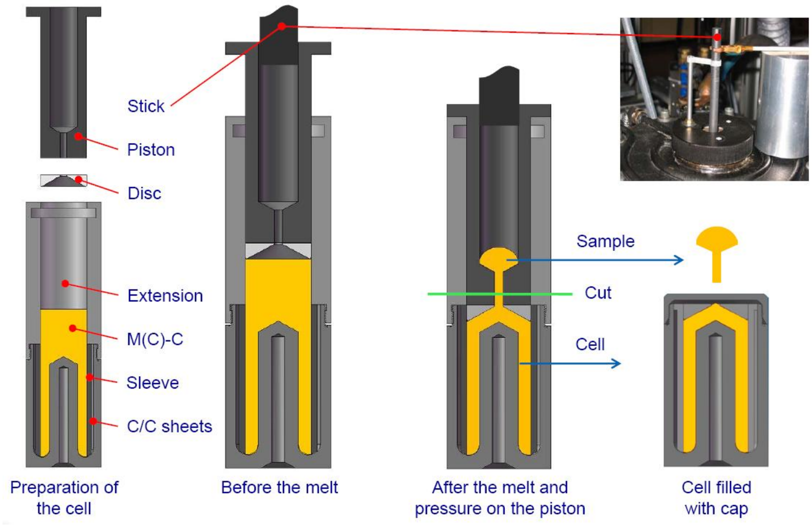

Figure 1. CNAM Piston Method for filling fixed points cells.

The assignment of the temperature value to the aluminum cells was performed by extrapolation from the temperature of the copper fixed point. The extrapolation was done by applying the Plank's law for radiation and to derive the unknown Al fixed point temperature from the ratio of the radiance of both fixed points. The comparison between the two fixed point blackbodies was done in the infrared (~1.6 µm) using an InGaAs photodiode. In order to perform a robust comparison of the aluminium and copper radiances, the energies emitted by both cells at the same wavelength were compared.

Forthcoming events

- EURAMET TC-T annual meeting, 24–27 April 2018, Borås, Sweden
- XIV European Association of Thermology Congress, 4–7 July 2018, Teddington, London, UK, http://www.eurothermology.org/congress2018/
- IMEKO XXII World Congress, 3–6 September 2018, Belfast, UK, http://www.imeko2018.org/
- InK2 project meeting, 7 September 2018, Belfast, UK
- 26th CGPM 13–16 November 2018, Versailles, France. Final voting for the redefinition of the SI, https://www.bipm.org/en/cgpm-2018/

Every nine months a newsletter of the project will be distributed. Please forward this newsletter to your colleagues. To register for this newsletter, send an email to ossi.hahtela/at/vtt.fi with subject 'register InK2 newsletter'. Additional information on InK2 can be found on the project homepage http://www.vtt.fi/sites/InK2/.

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Contact and further information

InK2 project is carried out by the following partners and institutions.

NPL	NPL Management Limited	UK
CEM	Centro Español de Metrología	Spain
CNAM	Conservatoire national des arts et metiers	France
INRIM	Istituto Nazionale di Ricerca Metrologica	Italy
LNE	Laboratoire national de métrologie et d'essais	France
PTB	Physikalisch-Technische Bundesanstalt	Germany
TUBITAK	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey
VTT	Teknologian tutkimuskeskus VTT Oy	Finland
Aalto	Aalto-korkeakoulusäätiö	Finland
CSIC	Agencia Estatal Consejo Superior de Investigaciones Cientificas	Spain
UP13	Université Paris 13	France
RHUL	Royal Holloway and Bedford New College	UK
SUN	Università degli Studi della Campania Luigi Vanvitelli	Italy
IPC-CAS	Technical Institute of Physics and Chemistry, Chinese Academy of sciences	China
NIM	National Institute of Metrology	China
VNIIOFI	Federal State-Owned Unitary Enterprise All-Russian Research Institute for Optical and Physical Measurements	Russian Federation

Coordinator:	Graham Machin	NPL	graham.machin/at/npl.co.uk
WP1: Measurement of T–T_{90} (430 K ... 1358 K)	Helen McEvoy	NPL	helen.mcevoy/at/npl.co.uk
WP2: Measurement of T–T_{90} (5 K ... 200 K)	Fernando Sparasci	CNAM	fernando.sparasci/at/cnam.fr
WP3: Novel Primary Thermometry	Livio Gianfrani	UniNA2	livio.gianfrani/at/unina2.it
WP4: Primary Low-Temperature Thermometry	Jost Engert	PTB	jost.engert/at/ptb.de
WP5: Creating Impact	Ossi Hahtela	VTT	ossi.hahtela/at/vtt.fi

Project homepage: http://www.vtt.fi/sites/InK2/

Project page at ResearchGate: RG/InK2 where you can follow the progress of the project and participate in discussion related to the new definition of the kelvin and its future implementation.

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