The Future of Temperature Sensing
Room 320 - Session TS-TuA

The Future of Temperature Sensing I

Moderators: Dr. Nikolai Klimov, National Institute of Standards and Technology, **Dr. Sesha Challa**, NIST-Gaithersburg

4:00pm **TS-TuA-8 Keynote Talk: The Transformation of Temperature Traceability**, ***Graham Machin FREng FRS,*** National Physical Laboratory, U.K. **INVITED**

In May 2019 the kelvin was redefined in terms of a fixed value for the Boltzmann constant, *k*. Since then global temperature traceability has been regulated through the Consultative Committee of Thermometry (CCT) *mise-en-pratique* for the definition of the kelvin (*MeP*-K-19).

The *MeP*-K-19 introduced a gradualist but transformational approach to temperature traceability. Whilst allowing for continuity in temperature traceability through the long defined temperature scales of ITS-90 and PLTS-2000, it opened, for the first time, the possibility for temperature traceability to be derived directly from the kelvin definition through use of a *MeP*-K-19 approved primary thermometry approach, such as acoustic gas thermometry or dielectric constant gas thermometry. Some of these approaches are currently close to maturity and likely to be implemented and trial comparisons in train before the end of the decade.

However, that form of traceability is essentially still traditional in that reference thermometers would still be calibrated at National Metrology Institutes (NMIs) and sent to calibration laboratories to act as reference standards for the calibration of user thermometers. The only difference, from a user perspective, is that thermodynamic temperature, T, rather than a defined scale (T_{90} or T_{2000}) would be disseminated to them. More radical traceability approaches, envisaged in the CCT Strategy 2030+, is the development of temperature sensors that provide traceability at the point of measurement. These could be conventional based self-validating thermometers, or reliable practical primary thermometers, that require no calibration, based on fundamental physical principles that would provide trustworthy thermodynamic temperature values for the lifetime of the application.

In this talk I will outline the kelvin redefinition, introduce the concept of traceability, describe the *MeP*-K-19 and its function and then go on to speak about emerging approaches to temperature traceability. This will be illustrated with examples ranging from traditional approaches to temperature traceability that disseminate T, to more radical approaches under development such as self-validating thermometers and practical primary thermometry such as Doppler broadening or ring-resonator thermometry.

4:45pm **TS-TuA-11 Dual-Mode Fiber-Optic Refractive-Index Gas Thermometry for Primary Calibration and Continuous Temperature Tracking to 1000 K**, *Musaddeque Syed,* ***Ming Han,*** Michigan State University

Accurate, drift-resistant temperature measurement is essential for harsh industrial processes, where conventional secondary sensors often degrade under sustained thermal and mechanical stress or experience radiation-induced drift in nuclear reactor environments. Refractive-index gas thermometry (RIGT) provides a driftless primary route to thermodynamic temperature measurement, but practical deployment has been limited by pressure-cycling requirements that reduce measurement speed and complicate field operation. Here, we advance an argon-filled, fiber-optic Fabry-Perot (FP) RIGT sensor into a dual-mode temperature metrology platform that combines absolute primary calibration with continuous temperature tracking up to 1000 K.

The thermometer consists of an external FP cavity formed at the end of a single-mode optical fiber and filled with argon gas. In primary mode, absolute thermodynamic temperature is determined from spectral fringe shifts measured between two pressure states and interpreted using a virial-coefficient refractivity model, eliminating dependence on empirical calibration. In secondary mode, the same fiber-optic FP sensor operates at a fixed pressure to continuously track temperature-induced optical path-length changes with faster temporal response. This mode provides practical monitoring capability between primary calibration points while retaining traceability to the underlying RIGT measurement framework.

We develop working equations for both primary-mode and secondary-mode operation, establishing a unified analytical framework for absolute temperature determination and continuous temperature tracking using the same fiber-optic FP sensor. The dual-mode operation is experimentally demonstrated from room temperature to 1000 K. The resulting architecture links the driftless accuracy of a primary gas thermometer with the compactness, remote interrogation capability, and deployment advantages of a fiber-optic FP sensor. This work establishes a practical pathway toward high-accuracy temperature metrology for extreme industrial, energy, nuclear, and process-control environments.

5:00pm **TS-TuA-12 A Projected Refractive Index Gas Thermometer Revisited**, ***Patrick Egan,*** National Institute of Standards and Technology (NIST)

In 1974, Colclough of the National Physical Laboratory UK lamented the difficulties associated with the primary thermometry methods: constant volume gas thermometry, acoustic gas thermometry, and Johnson noise thermometry. As an alternative to those established methods, Colclough projected a refractive index gas thermometer as a viable alternative for primary thermometry.

There were two oversights in Colclough's projections. The first is merely a minor point that the proposed refractometer system (gas cell in a Michelson interferometer) never worked! The second issue is that Colclough did not foresee the 2025 breakthrough "dispersion gas barometry" which derives thermodynamic temperature using simultaneous measurements of refractive index at widely separated wavelengths. Fifty year's after Colclough's original projection, I would now argue that refractive index gas thermometry has become superior to every other primary thermometry methodology.

My presentation will explain some key advantages of dispersion gas barometry. I will present a roadmap for primary thermometry covering the range 4 K to 1234 K using only two refractometers.

1. A. R. Colclough, "A Projected Refractive Index Thermometer for the Range 2--20 K," Metrologia 10, 73 (1974). https://doi.org/10.1088/0026-1394/10/2/006
2. Y. Yang, J. A. Stone, and P. F. Egan, "Demonstration of dispersion gas barometry," Physical Review Applied 23, 064041 (2025). https://doi.org/10.1103/z9zz-lqzh

5:15pm **TS-TuA-13 Wide-Temperature-Range Luminescence Thermometry**, ***Yuanbing Mao,*** Illinois Institute of Technology

Luminescence-based temperature sensing holds great promise thanks to their attractive properties including rapid response, high spatial resolution, and remote non-invasive detection, ultimately their applicability in chemically and electromagnetically harsh environments. Relevant to their practical use, a wide temperature sensing range is urgently required for thermometric phosphors along with high relative sensitivity. Herein, we have designed several thermometric phosphors for wide-temperature-range sensing in recent years. In this talk, I will focus on discussing relevant strategies to broaden the working range of thermometric phosphors with enhanced temperature sensitivity, such as intervalence charge transfer and thermally stable hosts, particularly negative thermal expansion compounds. Our work provides inspiration for exploring desirable wide-temperature-range thermometric phosphors insensitive to surface emissivity and reflected radiation with broad application potential.

5:30pm **TS-TuA-14 Group V Metalates as High-Temperature Thermosensitive Phosphors**, ***Federico Rabuffetti,*** Wayne State University

Refractory niobates and tantalates are ideal hosts for high-temperature thermosensitive phosphors activated with rare-earths.A distinct feature of these materials is their chemical tunability, which makes them ideal platforms to understand the interplay between crystal structure, electronic structure, and luminescence thermal quenching. This understanding provides the basis to exercise synthetic control over temperature-dependent luminescence and thermometric response.

In this talk I will use group V metalates to illustrate how we are approaching the challenge of establishing a set of crystal-chemical principles that enable the design of high-temperature thermosensitive phosphors. Synthesis, high-end structural analysis, and luminescence studies of dysprosium-doped $Ba_3MgTa_2O_9$ and Y_3NbO_7 will be described to demonstrate how chemical substitutions may be used to rationally tune structural and electronic features governing thermal quenching. From a luminescence thermometry standpoint, I will show that both phosphors are capable of temperature sensing up to 1200 °C, thus expanding the compositional library of high-temperature thermosensitive phosphors [1,2].

[1] M.R. Imer, A. Afugu; Z.-F. Liu; and F.A. Rabuffetti. Luminescence of Triple Perovskite $Ba_3MgTa_2O_9:Dy^{3+}$ Up to 1100 °C. *The Journal of Physical Chemistry C* **2024**, 128, 16628–16639.

[2] M.R. Imer and F.A. Rabuffetti. Luminescence of Y_3NbO_7:Dy Up to 1000 °C. *Journal of Luminescence* **2025**, 278, 121017.

Author Index

Bold page numbers indicate presenter