Selected Research Topic number: **SRT-s04**
Version: 1.0

Title: Metrology for quantum-based traceability of the pascal

Abstract

Presently, several conventional methods are required to realise the pascal in the 1 Pa - 100 kPa range with a variety of relative uncertainties in the 10^{-4} - 10^{-6} range. The Consultative Committee for Masses and Associated Quantities (CCM) and the EURAMET Technical Committee for Masses and Associated Quantities (TC-M) have identified the need for further improvement. This research aims to establish a metrological infrastructure for a traceable quantum-based pascal in the 1 Pa - 1 MPa range, for example by using Fabry-Pérot refractometer for high accuracy and the use of nitrogen as measuring gas. The novel methods should be evaluated in terms of transportability, long-term stability, working range, miniaturisation as well as flexible mode of operation.

Keywords

Pascal, pressure, molar density, quantum-based, Fabry-Pérot refractometry, nitrogen gas, *ab-initio* calculations, virial coefficients, vacuum.

Background to the Metrological Challenges

With the new International Unit System (SI), in which the Boltzmann's constant has no uncertainty, the performance of quantum-based pressure standards assessing molar density would, in principle, will be limited only by the uncertainty of *ab-initio* calculations of gas parameters. Work to realise a quantum-based pascal takes place at different National Metrological Institutes (NMIs), while significant progress has been made in recent years primarily within the EMPIR 18SIB04 QuantumPascal project, which has demonstrated that FP-based refractometry has the potential to replace the best conventional methods, especially in the low-pressure range where there is a strong industrial need for improved standards. Based on these results, this research aims to establish traceability to the redefined SI by a quantum-based pascal in Europe in the 1 Pa – 1 MPa range by the realisation of selected quantum-based instrumentations, as well as to develop means to disseminate the developed technology and its performance to the relevant stakeholders and industry.

Pressure assessments with precision in the 10^{-8} range and an extended uncertainty of $[(10\ \text{mPa})^2 + (10 \times 10^{-6}\ p)^2]^{1/2}$ have already been demonstrated. In addition, it has been shown that quantum-based primary pressure standards can be realised with microwave resonators and dielectric constant gas thermometry with relative uncertainties $u_r(p) \leq 8 \cdot 10^{-6}$ for pressures in the 800 kPa – 7 MPa range, providing independent methods compatible to piston gauges. However, the realisation of practical transfer standards requires the development of compact, less complex apparatus, for which FP-refractometers are ideal. In line with this, a compact system has already been developed for the measurement of gas pressure based on Rayleigh scattering, capable of working over a wide pressure range from 10 Pa to 1 MPa. This realisation provides a large dynamic range with excellent linearity (better 10^{-5}). Last, *ab-initio* calculations of the gas properties, required to realise the pascal with relative uncertainties in the order of ppm, are currently only available for helium and to a certain extent for argon. To successfully develop and employ quantum-based pressure standards it is necessary to have access to metrological reference data for other gas species. Nitrogen is a very attractive candidate in this regard since it is widely used in metrology and industry. However, despite its broad use, there is a lack of reference data, updated data on dielectric and density properties, while the uncertainty estimations are currently partially missing.

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 JRP shall focus on the traceable measurement and characterisation of the quantum-based pascal.

The specific objectives are

1. To develop high-accuracy primary pressure instruments based on Fabry-Perot (FP) refractometry for the traceability to the pascal and covering the 1 Pa to 30 kPa range. The target uncertainty is 2 mPa + 10 ppm (k=2).
2. To develop validated quantum-based methods (including FP-based techniques, Rayleigh scattering, and polarising gas thermometry methods) to enable transfer of calibration within the 1 Pa to 1 MPa range with a target uncertainty 5 mPa + 30 ppm (k=2). Applications should include gauge mode measurement, measurement of dynamical pressure and measurements with nitrogen and dry air medium. The concepts of miniaturisation and transportability should also be investigated.
3. To improve the metrological reference data and estimate the relevant uncertainties for the thermodynamic and electrodynamic properties of primarily nitrogen, i.e. density and dielectric virial coefficients, temperature dependent static and dynamic polarizabilities. The target uncertainty of the molar polarizability is in the order of a few ppm.
4. To verify that the developed instruments utilising the developed quantum-based methods are consistent with their combined uncertainties and with existing primary standards, as well as to assess their long-term stability.
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 (EMN Quantum, European initiatives like the quantum flagship), standards developing organisations (CCM WGPV, EURAMET TC-M, ISO TC112) and end users (key stakeholders from science and industry).

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.

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 18SIB04 and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.6 M€ for this project.

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 JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Develop an integrated self-sustaining European metrology infrastructure,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the industrial, scientific and regulatory sectors.

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 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.

Time-scale

The project should be of up to 3 years duration.