EMPIR Call 2018 – Health, SI Broader Scope, Normative and Research Potential

Selected Research Topic number: **SRT-s10**
Version: 1.0

Title: Towards quantum-based realisations of the pascal

Abstract

Recent advances in optical, microwave and dielectric measurement techniques, combined with the outstanding progress of quantum-based calculations of the permittivity, the refractive index and the density of atomic and molecular gases, have paved the way for the development of novel, improved pressure standards in the range between 1 Pa and 3 MPa. This SRT addresses the realisation of several methods that have the potential to become new primary standards of the pascal unit. Theoretical calculations would be needed to obtain superior metrological performance in comparison to conventional pressure and vacuum standards.

Keywords

Pascal, pressure, density, refractivity, permittivity, optical cavity, microwave resonator, interferometry, absorption spectroscopy

Background to the Metrological Challenges

In spite of the extensive number of applications of pressure measurements in nearly all sectors of scientific, social and industrial activities, the primary reference of this physical quantity extending over the wide range between 1 Pa and several MPa is still realised by measuring the height of a liquid of known density (typically mercury) in a manometer or, alternatively, by equilibrating pressure to the gravitational force exerted by weights of known mass through a piston gauge in a pressure balance. Both these dated reference methods require measurements that are traceable to the kilogram and the meter, and suffer from inherent limitations because of safety (recent World Health Organisation resolutions recommending the progressive reduction of human exposure to mercury and mercury compounds) and practical reasons (bulkiness, fragility, complexity of operation).

The forthcoming new definition of the SI encourages the exploration of more direct traceability paths which are routed in the fundamental laws and constants of physics. For the dissemination of the pascal such a route would indeed be available, and a primary standard could be based on the extremely precise determination of an optical or electrical quantity, like the refractive index or the permittivity of a gaseous substance whose density dependence can be accurately calculated from first principles. The validity and feasibility of this approach, using He as the calculable reference substance, was previously demonstrated using capacitors, microwave resonators, and interferometers. In this context, additional scientific and technological development of these promising methods is needed to extend their useful working range and demonstrate that their accuracy may significantly outperform that of conventional pressure standards.

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 metrology research of several methods that have the potential to become new primary standards for the SI unit of pressure, the pascal.

The specific objectives are

1. To improve the accuracy and extend the working range of quantum-based methods that have the potential to become primary standards of the SI unit of pressure, the pascal, by using several methods based on the determination of refractivity or permittivity. The target

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uncertainty and pressure ranges are: less than 500 ppm at 1 Pa, 10 ppm at 1 kPa and 5 ppm between 100 kPa and 3 MPa.

2. To explore the potential of alternative pioneering approaches and detection methodologies for the realisation of absolute and partial pressure standards, including superconductive microwave resonators, Rayleigh scattering, absorption spectroscopy of selected molecular species with very long optical pathways, and modulation techniques.

3. To develop improved ab-initio calculations of the thermodynamic and electromagnetic properties of gases (e.g. He, Ne, Ar, N_2) as needed to meet objectives 1 and 2. These properties include static and dynamic polarisability, the diamagnetic susceptibility along with dielectric- and density virial coefficients. For gases other than He, the accuracy of the calculations (targeted uncertainty contributions of 1 ppm to 5 ppm at 100 kPa, equivalent to an improvement of at least a factor of 5) to be validated by comparisons with the results from experiments using He as a calibrating reference substance.

4. To demonstrate the performance of the methods developed in 1 and 2 by comparison with conventional primary pressure standards such as liquid column manometers and pressure balances.

5. To facilitate the take-up of the technology developed in the project by end users, i.e. the scientific, metrological and industrial communities and standards developing organisations.

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 outside Europe 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.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 20 % of the total EU Contribution across all selected projects in this TP.

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,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the calibration laboratories and industry 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 EMPIR 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.