Universität Basel

Research Project

Quantum technologies for molecular precision spectroscopy

Third-party funded project

Project title Quantum technologies for molecular precision spectroscopy
Principal Investigator(s) Willitsch, Stefan ;
Organisation / Research unit
Departement Chemie / Chemische Physik (Willitsch)
Department
Departement Chemie
Project start 01.01.2022
Probable end 31.12.2025
Status Active

In recent years, impressive advances in the cooling, manipulation and quantum control of ultracold trapped atoms and atomic ions have been achieved which enabled spectroscopic measurements with an unprecedented precision. Similarly precise spectroscopic experiments on molecules open up a range of new scientific perspectives including tests of new physical concepts, the implementation of new frequency standards, accurate evaluations of physical theories such as quantum electrodynamics, precise determinations of fundamental constants and exact studies of the properties of molecules and their constituent particles. They also lay the foundations for applications of molecules in the realm of modern quantum science such as quantum information and quantum sensing. However, the complex energy-level structure of molecules and the absence of optical cycling transitions in most molecular systems constitute a major challenge for their state preparation, laser cooling, state detection, coherent manipulation and, therefore, precise spectroscopic characterisation.

Molecular ions confined in radiofrequency traps and sympathetically cooled by simultaneously trap- ped atomic ions have proven a promising route for overcoming these obstacles. We have recently devel- oped a new experimental scheme enabling the readout of the quantum state of a single trapped molecular ion without destroying the molecule and indeed the quantum state itself. This quantum-non-demolition technique enables spectroscopic experiments with four to five orders of magnitude faster duty cycles than previous destructive state-readout techniques and concomitant improvements in spectroscopic sensitivity and precision.

Such "quantum-logic" methods represent a paradigm change in the way spectroscopic experiments are performed on molecules. In the present project, we will harness the potential of this new approach to perform highly sensitive spectroscopic measurements on the hyperfine, rotational and vibrational energy-level structure of the homonuclear diatomic ion N+2 with unprecedented precision. N+2 has previously been identified as an ideal system for molecular precision measurements. In a recent comprehensive the- oretical screening, we have explored suitable clock transitions within the energy-level manifolds of N+2 which will be characterised experimentally in the present project. We will make use of a newly established infrastructure for the distribution of the Swiss primary frequency standard at the Swiss metrology institute METAS in Berne to our laboratory in Basel via an optical fibre link. Referencing all our laser sources to the METAS standard will allow us to reach an absolute measurement precision on the level of 10−15 thus establishing a new frontier in the precision of spectroscopic measurements on molecular ions across different frequency domains. The clock transitions to be probed here are predicted to also exhibit excellent coherence properties and are therefore attractive candidates for molecular quantum bits with prospective applications in quantum science.

In summary, using quantum-logic techniques for state readout in combination with remote calibration to the Swiss primary frequency standard via a fibre link, the present project will introduce new methods for molecular frequency metrology and establish new limits in the measurement precision of the hyperfine, rotational and vibrational spectroscopy of molecular ions. In this framework, we will also perform the first direct rotational spectroscopy on a homonuclear diatomic ion. Besides their immediate relevance for molecular spectroscopy, the targeted results are expected to be of importance for the wider field of frequency metrology and the development of new frequency standards, for atomic, molecular, optical and chemical physics by introducing new concepts to probe and interrogate molecules, for quantum science by establishing quantum bits with very high coherence properties and also for fundamental physics by setting new constraints on a possible time variation of the electron-proton mass ratio.

Financed by
Swiss National Science Foundation (SNSF)

Add publication

Add documents

Specify cooperation partners