ESR5: High-efficiency preparation of a single quantum state of a molecular ion and a high-precision spectroscopic determination of a fundamental mass ratio

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Host Institution: Heinrich Heine University of Düsseldorf

Duration: 36 months

Planned secondment: Aarhus University

Description: In our group, we are focusing on a particular molecular ion, HD^+. This is a useful model system for testing techniques that can be of more general utility in the field of heteronuclear molecular ions, but it is of significant interest also in its own right, beign a fundamental quantum system.

HD^+ is a three-body bound quantum system that can be accurately described ab initio by Quantum Electrodynamics, using as input certain fundamental constants, in particular the Rydberg energy and the two mass ratios of the three constituent particles. A comparison between experimental HD^+ transition frequencies and the ab initio results therefore provides a test of the validity of theoretical treatments, and/or a determination of these fundamental constants. At present, the experimental inaccuracies of the transition frequency measurements is still higher than the theoretical or fundamental constants inaccuracies, resulting in an on-going experimental challenge.

We have performed many seminal experiments on cold molecular ion spectroscopy over the last decade, including laser-based rotational cooling, resonance-enhanced multi-photon dissociation, pure rotational excitation, fundamental vibrational spectroscopy. We also demonstrated addressing of individual hyperfine states of ro-vibrational levels by excitation of individual hyperfine transitions, and controlled transfer of population into a selected hyperfine state. On the theory side, we have worked extensively on the systematic frequency shifts of HD^+, a very important topic if precision measurements are pursued.

References on this work can be found in the publication list at www.exphy.uni-duesseldorf.de.

In the open position, developments will be pursued that are aiming at increasing significantly the efficiency and accuracy of precision spectroscopy of HD^+.

In detail, the task will be:

- Develop an ion trap for storing a single atomic and a single molecular ion, sympathetically cooled.
- Integrate a laser-based scheme for population effectively a single hyperfine state
- Integrate a scheme for reading out efficiently the population of a single hyperfine state
- Apply preparation and read-out techniques to various forms of high-resolution spectroscopy (radio-frequency, pure rotational, and ro-vibrational spectroscopy)
- Compare the measured transition frequencies with the ab-initio theory values in order to validate the ab-initio theory calculations, and combine the results of the various spectroscopic measurements to determine an improved value of the mass ratio electron mass - reduced nuclear mass
- The work will be done in a team comprising several Ph.D. and Master's students, a senior researcher and supported by a team of electronics engineers. See also our flyer.
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