Sympathetic and direct laser-cooling of molecular ions

Kenneth Brown
Georgia Institute of Technology

Molecules have a richer internal structure than atomic ions which can provide benefits for precise measurement of fundamental constants and their possible time variation. The internal structure also presents challenges for the manipulation of the molecular state. An advantage of molecular ions is that the external degrees of freedom can be cooled by Coulombic interaction with laser-cooled atomic ions. The result are well-ordered ion structures called Coulomb crystals that can be used to enhance molecular ion spectroscopy. I will present our work on single-molecule dissociation spectroscopy of CaH+ in Coulomb crystals [1] and on achieving ground state cooling of CaH+ [2] for future non-destructive spectroscopic measurements. Finally, I will discuss the prospects of direct laser-cooling of molecular ions, in this case BH+, [3] and present our preliminary results on the trapping and sympathetic cooling of this molecular ion.

[1]Observation of vibrational overtones by single molecule resonant photodissociation, N. B. Khanyile, G. Shu, and K. R. Brown, Nat. Commun. 6, 7825 (2015)
[2]Sympathetic cooling of molecular ion motion to the ground state, R. Rugango et al., New J. Phys. 17, 035009 (2015)
[3]Challenges of laser-cooling molecular ions, J. H. V. Nguyen et al., New J. Phys. 13, 063023 (2011)

Interfacing Single Ions and Single Atoms

Matthias Keller
University of Sussex

The complementary benefits of trapped ions and photons as carriers of quantum information make it appealing to combine them in a joint system. Ions provide low decoherence rates, long storage times and high readout efficiency, while photons can travel easily over long distances. To interface the quantum states of ions and photons efficiently, we use calcium ions coupled to an optical high-finesse cavity via a Raman transition.

Utilizing fibre cavities we aim to strongly couple single and multiple ions to a cavity mode which facilitates the deterministic transfer of the quantum state of trapped ions and the polarisation of single photons. In my presentation I will give an overview of the problems and possible solution of combining small optical cavities and ion traps.

At Sussex, we also investigate larger optical cavities which can serve as quantum buses to entangle ions within the same cavity mode. Measuring the cavity emission while driving a cavity assisted Raman transition of two ions can project the ions into an entangled state. Increasing the number of ions in the cavity mode can be employed to generate multi-ion entangled states. We have optimally coupled up to five ions to the same cavity mode and determine their localisation, a prerequisite for the generation of multi-ion entangled states.

Towards Optical Clocks based on Ion Coulomb Crystals

T.E. Mehlstäubler
QUEST-Institute at PTB, Bundesallee 100, 38116 Braunschweig, Germany

In order to exploit their full potential and to resolve frequencies with a fractional frequency instability of 10^{-18} and below, optical ion clocks need to integrate over many days to weeks. For the characterisation of systematic shifts of the clock, as well as for applications, such as relativistic geodesy, the long averaging time scales pose severe limits. Scaling up the number of ions for optical clock spectroscopy is a natural way to significantly reduce integration times, but was hindered so far by the poor control of the dynamics of coupled many body systems, on-axis micromotion and systematic shifts due to interacting ions. However, ion species, such as Yb^+, In^+ or Al^+, with low or zero quadrupole moments of the clock states are interesting candidates for frequency standards based on multiple ions.

We will detail on how a fractional inaccuracy of 10^{-18} can be reached in such systems. We implement linear chains of Yb^+ and In^+ ions for a first evaluation for optical clock operation and detail on the expected uncertainties. We will present a first evaluation of the expected uncertainty in scalable ion traps.

For optimum control of the ion motion and lowest frequency shifts due to micromotion and excess heating rates we have developed a new segmented ion trap with on trap filter boards and a protected spectroscopy segment. The operating prototype trap with minimized axial micromotion allows us to trap and cool large ion Coulomb crystals with lowest heating rates. To reduce systematic shifts due to blackbody radiation, this trap design is transferred to an AlN based chip trap. We will present an evaluation of the uncertainty of relative frequency shifts stemming from the ion trap at the level of 10^{-20}.