Fiber amplified diode laser at 1762 nm for quantum simulation/computing using strings of ultracold Ba^+ ions

Level: Bachelor/Master
ECTS: 10 or 15 / 45-60
Topic:
With the aim of preparing smaller strings of ions near their motion ground state with respect to their different normal modes for quantum simulation/computing purposes, the project will focus on the establishment of a high-power laser source (1 Watt output power) with a very narrow spectral linewidth (1 kHz) for so-called sideband laser cooling of Ba^+ ions on the $^2S_{1/2} \leftrightarrow {}^2D_{5/2}$ quadrupole transition at 1762 nm. This high-performance laser source will be achieved through sending a few mW of 1762 nm light from a commercial diode laser (Toptica) through a fiber amplifier from our collaborating Danish laser company NKT Photonics. While test of the source will take place in the Ion Trap Group, in a longer perspective the laser will be applied in more complex quantum simulation/computing setting at the American company IonQ, with whom the Ion Trap Group also collaborate.

Research activities:

- Integration a low power diode laser with an high-power fiber amplifier.
- High-precision frequency measurements using an optical frequency comb.
- Testing the laser system in sideband cooling experiments of Ba^+.
- Introduction to ion trapping and laser cooling methods.

Skills gained:

- Experience with optics including optical fibers, polarization optics and acousto-optic modulators.
- Experience with external cavity diode lasers (ECDL) and the most advanced frequency measuring tools.
- Experience with fiber laser amplifiers
- Experimental interfacing using ArtiQ (Python based) and data analysis.

The Ion Trap Group
Contact: drewsen@phys.au.dk

Calibration of an electrospray ion source for photon recoil spectroscopy of single complex molecular ions

Level: Bachelor/Master
ECTS: 10 or 15 / 45-60
Topic:
In general, spectroscopy of molecular ions leads to important information on their internal structure. At the ultraprecise level, which is provided by photon recoil spectroscopy (PRS), it allows for many fundamental investigations ranging from tests of quantum electrodynamics (QED), improved constraints on the electron-to-proton-mass ratio, as well as on the electron dipole moment, to, via comparison with astrophysical data, detecting drifts over time in natural constants. Complementarily, this technique enables the observation of single photon absorption in single molecular ions constitute a unique setting for investigations of a range of properties and dynamics in complex molecules ranging from determination of chirality over collective quantum effects in photo-absorption to energy transport in single molecular ions. In the Ion Trap Group, we have recently built a so-called electrospray ion source which can produce a wide range of molecular ions, which will be sympathetically
cooled by single Ba^+ ions to establish the setting for PRS. The project will be focused on calibrating this ion source in terms of ion yields at the experimental ion trap.

Research activities:

- Electrospraying of various complex molecular ions
- Mass-to-charge separation of produced ions.
- buffer gas cooling of complex molecular ions .
- Lifetime measurements of accumulated ions in different ion traps.

Skills gained:

- Experience with the concept of electrospraying.
- Experience with ion optics.
- Experience with ion trapping.
- Experience with buffer gas cooling
- Experience with quantitative data analysis.

The Ion Trap Group
Contact: drewsen@phys.au.dk

Sideband laser cooling of Ba^+ ions in a cryogenically cooled linear Paul trap

Level: Bachelor/Master
ECTS: 10 or 15 / 45-60
Topic:
With the aim of sympathetically cooling single complex molecular ions to the quantum ground state for performing photoabsorption investigations at the single photon level, we first need to trap and laser cool a single Ba^+ ion to the motional ground state in our cryogenically cooled (T ∼ 6 K) linear Paul trap. The first step towards this intermediate goal has been Doppler laser cooling of the Ba^+ ions by simultaneously driving the $^2S_{1/2} \leftrightarrow {}^2P_{1/2}$ and $^2D_{3/2} \leftrightarrow {}^2P_{1/2}$ transitions using lasers at 493 nm and 650 nm, respectively, to reach few mK temperatures. The next step, which is the focus of this project, is so-called resolved sideband laser cooling of a single Ba^+ ion to the motional ground state by driving the $^2S_{1/2} \leftrightarrow {}^2D_{5/2}$ quadrupole transition.

Research activities:

- Setting up beam paths for sideband laser cooling of Ba^+ .
- Testing the lasers necessary for loading and cooling of Ba^+.
- Isotope selective photoionization of barium.
- Doppler and sideband laser cooling of Ba^+.
- Sympathetic cooling of complex molecular ions.

Skills gained:

- Experience with optics including optical fibers, polarization optics and acousto-optic modulators.
- Experience with external cavity diode lasers (ECDL) and the most advanced frequency measuring tools.
- Experience with radio-frequency electronics.
- Experimental interfacing using ArtiQ (Python based) and data analysis.

The Ion Trap Group
Contact: drewsen@phys.au.dk

Laser spectroscopy of Li atoms

Level: Bachelor
ECTS: 10 or 15
Topic: How does an ion quantum computer behave inside a Bose-Einstein Condensate? To help the Ion Trap Group answer this question, you will set up a high-tech laser and use it to measure an atomic-transition in Lithium. From the recorded data you will analyze the spectral width of the transition. You will investigate the main contributions that lead to broadening of the natural linewidth and you will explore means to reduce these effects. The laser frequency will then be referenced to the atomic transition with an electronic feedback. The stabilized laser will allow to trap atoms and bring them to ultracold temperatures and you can be involved in all steps towards this goal. The project will give you hand-on experience in controlling atoms with light. Atom-light interaction is a key ingredient for quantum computation and quantum information.

Research activities:

- Install a commercial high-end Laser and optical set up
- Measurement of the $^2S_{1/2} \rightarrow {}^2P_{3/2}$ transition in Li
- Analysis of measured line and broadening effects
- Measure Doppler-free spectroscopy
- Use an atomic transition to reference the laser frequency

Skills gained:

- Hand-on experience in cutting edge atomic physics laboratory
- Experience in manipulating atoms with light
- Knowledge about atom-light interaction and laser cooling of atoms
- Insides into the research fields of ultracold atoms and trapped ions

The Ion Trap Group
Contact: drewsen@phys.au.dk

Pulsed laser cooling of ion Coulomb crystals in linear rf traps

Level: Bachelor/Master
ECTS: 10 or 15 / 45-60
Topic: While linear rf traps have been the preferential setup for research towards ion trap based general quantum computing, Penning traps have the past years been leading the impressive development in the field of quantum simulation in two-dimensional cold ion systems (ion Coulomb crystals). Since linear rf traps are considerable cheaper and more flexible than Penning traps, it would be interesting if cold planar ion crystals could be formed in rf traps as well. This possibility has so far been hampered by the so-called fast rf microtion of ions positioned away from the single rf-free axis of the linear rf trap, which lead to extremely large Doppler shifts and hence inefficient cooling by cw laser beams. In recent experiments we have, however, proven that it is indeed possible to reach very low laser cooling temperatures, if pulsed laser light synchronized with the rf trap fields is applied. In this project we want to implement the pulsed cooling scheme in an linear Paul trap, with an integrated optical cavity, using the state of the art ArtiQ control system.

Research activities:

- Get familiar with various laser-cooling schemes
- Devise optimal schemes for pulsed laser cooling of planar ion systems
- Implement and optimize advanced control and laser cooling schemes.

Skills gained:

- Experience with the semi-classical theory for atom-light interactions
- Experience with basics of semi-classical laser cooling theory
- Experience with the functioning of linear rf traps
- Insight into Coulomb crystals and their properties
- Experimental interfacing using ArtiQ (Python based) and data analysis.

The Ion Trap Group
Contact: drewsen@phys.au.dk