Optimal control of trapped ions – experiment

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Background

Ions that are trapped with electric and magnetic fields and manipulated with laser beams are one of the most promising systems to implement quantum algorithms, quantum simulations or also to perform high precision metrology. An important requisite for all such tasks is the cooling of the motion of the stored ions close to their quantum mechanical ground state, combined with extremely high accuracy of all subsequent manipulations.

Our trapped ion experiment allows us to store and manipulate rather large crystals of ions (as depicted in Fig.1), but since the number of motional modes grows with increasing number of ions, cooling and coherent manipulation of trapped ions is very challenging for large systems. Typical manipulations are based on selecting desired processes via their resonance condition, such that undesired processes are simply off-resonant. Targeting high fidelity operations and working with large systems (with many closely spaced transition frequencies), this simple principle is no longer sufficient. It is, however, possible to design temporally shaped control pulses such that undesired transitions are suppressed by destructive interference while desired processes are allowed because of constructive interference. The MRes phase of this project will constitute preparatory experimental work characterising the effect of undesired transitions on the achieved cooling in our trap, mainly for single ions. In the PhD project, you will work in the lab on the experimental implementation of the control sequences that will be developed by theoretical collaborators, including for larger numbers of ions.

Six month project

The Penning trap apparatus is a very complex system and it takes a few weeks to become familiar with its operation and to learn how to run the apparatus successfully. This involves learning how to use various types of laser; how to set up locking systems to stabilise the laser frequencies; how to load the ion trap; how to achieve Doppler cooling and reduce the number of ions in the trap to the desired number; and how to achieve efficient sideband cooling to the ground state of the motion reliably for single ions and very small ion Coulomb crystals. Once you have mastered this, initially working alongside current PhD students, you will investigate the current limitations on efficient sideband cooling arising from unwanted transitions that are driven off resonance by the sideband cooling laser. You will then start to develop the necessary practical techniques for implementing optimised sideband cooling protocols and carry out initial experiments to demonstrate improvements over conventional techniques.

PhD project

In your PhD project you would see theoretical findings developed in the theory group becoming experimental reality. The first goal would be to improve the cooling of the ions [2]. You will also work on other aspects of the ion trap setup in order to optimise ion coherence times and gate fidelities through improved design of the apparatus and development of experimental protocols that best preserve the delicate quantum state of the ions. Once this is achieved, you would focus on the efficient implementation of multiple coherent operations (quantum gates) with small numbers of trapped ions, further developing the optimal control techniques from the MRes project.

This project is part of a larger theory-experiment collaboration. Goal of the project is that you will initially familiarise yourself with the experimental procedures and implement optimal control ideas; during your experimental work you would be in direct contact with theory, who will take into account the experimental imperfections identified by you. Together with the theorists you would then work towards the elimination of such imperfections.

Please get in touch with Richard (620 Blackett, r.thompson@imperial.ac.uk) or Florian (Level 12 EEE, f.mintert@imperial.ac.uk) for a chat.