Experiments towards quantum information with trapped Calcium Ions

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Ground state cooling and coherent manipulation of ions in a rf-(Paul) trap is the prerequisite for quantum information experiments with trapped ions. In our experiments we have used two different traps, a conventional 3D-quadrupole trap and a linear trap. In both traps we have cooled one and two $^{40}Ca^{+}$ ions to the ground state of vibration with up to 99.9 % probability. To this end we used a continuous resolved sideband method where we drive the $S_{1/2}$ $D_{5/2}$ quadrupole transition (@ 729 nm) and repump the ion to the ground state via the $D_{5/2}$ $P_{3/2}$ dipole transition (@854 nm). Efficient cooling is achieved on the timescale of a few ms [1].

Starting from |n=0_ we have demonstrated coherent quantum state manipulation on the optical $S_{1/2}$ $D_{5/2}$ quadrupole transition at 729 nm. Up to 30 Rabi oscillations within 1.4 ms have been observed. We find a similar number of Rabi oscillations after preparation of the ion in the |n=1_ state. To further characterize our system we explored the dependence of cooling efficiency on the motional frequencies in the trap and the role of parasitic off-resonant excitations while coherently driving the qubit transition. We also characterized the motional heating from the ground state and found rates of 1 quantum per 190 ms (70 ms) for 4 MHz (2 MHz) trap frequency in the axial (radial) trap direction.

In the linear quadrupole rf-trap with 700 kHz trap frequency along the symmetry axis (2 MHz radial) the minimum ion spacing is more than 5 μm for up to 4 ions. We are therefore able to individually address the ions with our recently developed optical addressing channel [2] and work towards preparation of coherently entangled states with two and more ions in this setup.

[1] Ch. Roos, Th. Zeiger, H. Rohde, H. C. Nägerl, J. Eschner, D. Leibfried, F. Schmidt-Kaler, and R. Blatt, *Phys. Rev. Lett.* **83** 4713 (1999).

[2] H.C. Nägerl, D. Leibfried, H. Rohde, G. Thalhammer, J. Eschner, F. Schmidt-Kaler, and R. Blatt, *Phys. Rev. A* **60** 145 (1999).