Crystalline ion structures in a Paul trap

M. Block, A. Drakoudis, H. Leuthner, P. Seibert and G. Werth

Department of Physics, University of Mainz
Staudingerweg 7,55099, Mainz, Germany
Tel +49-6131-3923666, Fax +49-6131-3925169
E-mail: werth@mail.uni-mainz.de

Laser cooled ions are well suited for precision spectroscopy and frequency standard applications [1]. Recently there has been growing interest in linear ion strings for quantum computation following the proposal of Cirac and Zoller [2]. Since the first observation of ion crystals by Diedrich et al. [3] and by Wineland et al. [4] in 1987 a lot of theoretical and experimental work has been performed to investigate the formation of ion crystals under different conditions. We have observed crystalline structures formed by laser cooled Ca^+ ions in a 3-dimensional confining potential for different ratios of the potential strength in axial and radial direction [5]. The potential has been realized using a linear Paul trap with appropriate voltages applied to the electrodes. The ions are detected spatially resolved by a CCD camera. For radial confining potentials stronger than the axial potential we find linear structures with a continuous transition from strings to helices with decreasing potential asymmetry, where the symmetric case is realized for an equal potential strength in all directions. Helical structures assume two stable configurations which are mirror images of each other with transitions between the two configurations (Fig.1). The transitions are possibly induced by collisions with neutral background atoms and happen at a rate of 5 per second at a background pressure of $1 \cdot 10^{-10}$ mbar.

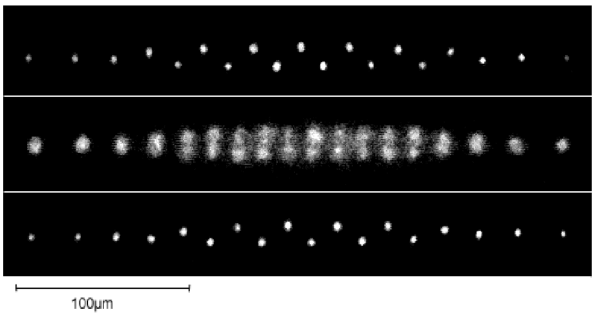

Figure 1: Zigzag shaped ion crystal consisting of 19 ions. (a) and (b) show the two different orientations observed which are nearly mirror images. (c) shows the same crystal with longer observation time (10s) of the camera. Flipping between the two orientations results in a washed out pattern.

When a quasi 2-dimensional harmonic potential is formed we observe ring structures (Fig. 2) with a given maximum ion number per ring. When the maximum ion number is reached occupation of a new ring starts in a similar fashion as for the periodic system of elements. The experiment was performed with up to 19 ions.

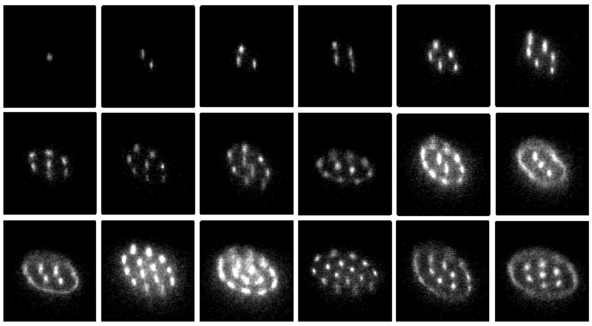

Figure 2: Periodic system of 2d crystals for one up to 19 ions. The width of one picture is 123 μm The ions form concentric shells with a given number of ions per shell. The next shell would be started for 32 ions.

Our observations are essentially in agreement with molecular dynamics calculations in static 2-dimensional potentials [6, 7]. For those conditions it is predicted that a 2d Thomson atom is formed and the configurations follow a Mendeleev-type table [6].

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