Identification and Non-destructive State Detection of Molecular Ions

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Cold molecules have a multitude of applications ranging from high resolution spectroscopy [1] and tests of fundamental theories [2,3,4] to cold chemistry [5,6] and, potentially, quantum information processing [7]. Prerequisite for these applications is the cooling of the molecules' motion and its non-invasive identification. Furthermore, the internal state of the molecules needs to be prepared and non-destructively detected.

The cooling of the motion and trapping of molecular ions can be accomplished by trapping them in an rf-trap alongside laser cooled atomic ions. The trapped ions form crystal like structures (Coulomb crystals) in which the ions are well localised within a volume in the order of μm^3.

We have developed a novel technique to measure the average charge to mass ratio of trapped ions with high precision by broadband excitation of the ions' COM-mode motion and measuring their laser induced fluorescence [8]. The FFT of the fluorescence's autocorrelation provides the COM-mode spectrum with a good SNR for measurement times as low as 100ms and kinetic energy injections of less than a few mK. We have employed this method to observe charge exchange reactions between different calcium isotopes and to measure the mass of a range of calcium isotopes. Chemical reactions between neutral molecules/atoms and trapped molecular ions can be investigated using this method by analysing the fluorescence of atomic ions which are trapped alongside the molecular ions in order to sympathetically cool them. Due to the precision of this method, reaction rates and branching rations can be measured even with large ion crystals (up to 100 ions). The method is limited only by the required interrogation time and the motional coupling of the constituents of the mixed ion crystal.

While blackbody assisted laser cooling was recently demonstrated [9,10], the nondestructive state detection is still beyond current experiments. Employing state selective laser induced dipole forces we aim to detect the internal state of molecular ions by mapping the state information onto the ions' motion [11]. The scheme promises mitigation of the effect of laser polarisation and the distribution of population across Zeeman sublevels and it may be applicable for a larger number of simultaneously trapped molecules.

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