A challenge of performing ion trap quantum computation with chains of ions is the heating of the trap vibrational modes. Trap heating can result in unwanted occupation of vibrational modes and a reduced fidelity for two ion gates. To combat this, specific ions within the chain can be tasked with cooling the entire chain via sympathetic cooling. The strength of the interaction between the cooling laser and cooling ion may have a significant effect on how efficiently the chain is sympathetically cooled. This interaction can be controlled via the intensity and detuning of the cooling beam as well as the time the cooling ions spend interacting with the cooling laser versus thermalizing with the ion chain. By using separate isotopes of Ca, we can construct a chain of cooling and information ions with each isotope interacting with its resonant cooling laser independently. By adjusting the aforementioned interaction parameters and measuring the sideband spectrum of the information ions, we will be able to find the most efficient sympathetic cooling parameters.

In these experiments, we trap two differing Ca isotopes: \(^{40}\text{Ca}\) and \(^{44}\text{Ca}\). Initially, we hope to chain 3 ions together by first cooling a single \(^{44}\text{Ca}\) ion with a 397 nm laser. Our next goal is to expand to multi-ion chains in planar Paul traps in support of the MUSIQ collaboration. We have so far applied two techniques: spectroscopy of the \(4^2\text{S}_{1/2} \leftrightarrow 4^2\text{P}_{1/2}\) transition and spectroscopy of the \(4^2\text{S}_{1/2} \leftrightarrow 3^2\text{D}_{5/2}\) transition. In both cases, while the spectroscopy ion is probed, the second ion sympathetically cools the first and the effectiveness of this interaction can be evaluated through the spectroscopy ion’s fluorescence.

**Ca\(^{+}\) Energy Levels and Isotope Shifts**

Our two techniques require spectroscopy of specific transitions in Ca\(^{+}\). In both cases, our collected signal is spontaneously emitted 397 nm photons generated by driving the \(4^2\text{S}_{1/2} \leftrightarrow 4^2\text{P}_{1/2}\). In both cases, an 856 nm repumper laser is necessary to avoid trapping the Ca\(^{+}\) in the metastable \(3^2\text{D}_{5/2}\) state. Additionally, for spectroscopy of the \(4^2\text{S}_{1/2} \leftrightarrow 3^2\text{D}_{5/2}\), a 729 nm laser is necessary for shelving, while an 854 nm laser is necessary for pumping back to the ground state after measurement.

Due to the larger atomic mass of \(^{44}\text{Ca}\), the atomic resonances experience isotope shifts with respect to the \(^{40}\text{Ca}\) levels:

\[
\Delta_{397} = 842 \text{ MHz} \quad \Delta_{866} = -4.495 \text{ GHz}
\]

Our initial experiments with spectroscopy of the \(4^2\text{S}_{1/2} \leftrightarrow 4^2\text{P}_{1/2}\) transition continuously probed both ions and the resulting peak shapes were difficult to analyze. By increasing collection efficiency, we will be able to use even lower \(s_{\text{cool}}\) values resulting in less cooling of the spectroscopy ion and better measurement of the temperature. Currently, for spectroscopy of the Zeeman levels it is not obvious that there is any change in \(n\) for an increase in \(t\), \(\Delta_{\text{cool}}\), or \(s_{\text{cool}}\) but this may be due to high values of \(n\) which requires very accurate measurement of our sideband heights (for example, \(r = 1.034\) for \(n = 29\)). In the multi-ion data we include, we see values of \(r\) implying \(n = 4\) due to noise.

To increase the reliability of our sideband data, we will implement increased averaging of sideband spectra, only probe the first sidebands at a higher resolution to more clearly image the peak, and switch which isotope we use for cooling and which we use for spectroscopy. Another approach would be to initially sideband cool both ions such that increases in \(n\) result in a larger \(r\). When we have refined these techniques, we will move onto larger ion chains as well as testing sympathetic cooling in planar ion traps.

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