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Setting up a high performance quantum computing experiment with trapped Barium ions

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Our project aims at setting up an ion-trap based, high-performance quantum computer, to push the current limits of gate fidelities and SPAM errors. We want to achieve such by using Barium as our qubit platform, which offers some key advantages over its most prominent competitors Calcium and Ytterbium. One example are the laser wavelengths required to interact with Barium, which are suited for integrated optics, further enhancing scalability and future on-chip implementations. The long lifetime of its optical qubit leads to a longer T1 time by more than an order of magnitude. The low-field optical clock qubit in one of Bariums isotopes, as well as the possibility of using hyperfine ground-state qubits push T2 times by about two orders of magnitude when compared to similar transitions in Calcium 40.

The heart of our setup is a standard Paul trap. It is situated inside a titanium vacuum chamber. The decision to move from stainless steel to titanium was made, as the rate of hydrogen outgassing for titanium is more than a factor of 10 smaller, which should also result in a correlating decrease in achievable pressure. A first characterisation of the setup via collision rates of the ions, which was measured to be 0,00029(1) /ion/minute, about a magnitude lower than what can be found in other room temperature ion traps in our laboratory, confirmed as much.

One big positive of using Barium is the long lifetime of its D5/2 state, which is commonly used for optical qubits, or for readout. With 30 seconds, it is more than an order of magnitude longer than in Calcium, and more than three compared to Ytterbium. Due to this, combined with the higher detection efficiency due to the higher quantum efficiency of EMCCD cameras at 493 nm rather than 397, or 370 nm, and a high numerical aperture in our setup of 0.6, one can reach much higher readout fidelities. Though we are not yet able to prepare states with high purity, or perform gates, first measurements allow us to estimate the readout error in our setup to be at, or just below 10ˆ-5.

The next steps, before we can start measuring coherence times and testing different gate schemes, is to optimise state preparation. For Barium 137, an isotope with non-zero nuclear spin, there are new techniques, for example by incorporating a microwave, that allow error rates as low as 1.1*10ˆ-5. The long-term goal of the project is to push the current limit of single qubit, and entangling gates. To achieve such, we will make use of single qubit Raman gates between hyperfine ground-states at 532 nm on the one hand, and new entangling gate schemes, such as transversal gradient gates or counterpropagating light-shift gates, as well as more established ones such as Mølmer–Sørensen style gates, also with Raman transitions at 532 nm. The calculated infidelities, given the known experimental parameters in our setup, are in the low 10ˆ-5 for single qubit, and 10ˆ-4 for entangling gates.

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