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Technical challenges of quantum computing with radioactive ^{133}Ba^{+} ions

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A large scale quantum simulator will provide the necessary tools for unparalleled scientific development. The challenges to build such a device are centered around the realization of a universal set of high fidelity quantum gates, that can be maintained in a system of many qubits. In the case of trapped ion devices of intermediate size, i.e. several tens of ions, the most natural approach to reach this goal is to realize long ions chains.

Here we provide the technical details of such an intermediate scale trapped ion quantum computer using ^{133}Ba^{+} qubits [1]. ^{133}Ba has nuclear spin $I = 1/2$ which allows for hyperfine "clock"qubits which are insensitive to magnetic fields and can be driven by Raman transitions. Additionally, the transition wavelengths are in the visible, allowing for off the shelf optics and fibre components.

However, ^{133}Ba is a radioisotope of Barium with a half life of 10.5 years. While this is not a limiting factor in terms of qubit lifetime, it requires careful considerations in terms of radiation safety. Primarily it is desirable to work with minimal quantities of the radioisotope. As such, loading with an oven is not appropriate. Instead, we load using laser ablation to provide short bursts of atomic flux from BaCl ablation targets of our own design. Additionally we give details of target fabrication and testing.

Secondly, the BaCl solution used in the target fabrication process only offers an abundance of synthetic ^{133}Ba on the order of $\sim 2\%$. Thus, loading long ion chains consisting of only ^{133}Ba must involve a process of isotope selection. We discuss the different techniques for achieving pure chains of order 50 ions, and present experimental work towards this with natural abundance samples. The required isotope selectivity is achieved by making use of the monolithic 3D microfabricated trap [2] in our experiment, which provides the necessary control to shuttle verified species from a loading zone to the trap centre.

[1] D. Hucul, J. E. Christensen, E. R. Hudson, and W. C. Campbell, "Spec-troscopy of a synthetic trapped ion qubit", Physical review letters, vol. 119, no. 10, 2017.

[2] P. See, G. Wilpers, P. Gill, and A. G. Sinclair, "Fabrication of a monolithicarray of three dimensional si-based ion traps", Journal of microelectrome-chanical systems, vol. 22, no. 5, 2013.

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