A quantum spin heat engine with trapped Yb^+ ions

L. McClelland[a], E. Streed[a], J. Vaccaro[a], M. Baker[a,b]

[a] *Centre for Quantum Dynamics, Griffith University, Nathan, QLD 4111, Australia.*

[b] *Quantum Technologies, Electronic Warfare Operations, Sensors & Effectors Division, Defence Science & Technology Group.*

Heat engines convert the energy in heat into usable work. Classical heat engines are limited by the Carnot efficiency, which is a limit imposed by classical thermodynamics. The recent proposal of entirely quantum heat engines[1, 2] could exhibit efficiencies surpassing this classical limit by leveraging entropy transfer from a thermal bath into a spin reservoir.

To realise a demonstration quantum heat engine, we use a trapped $^{171}Yb^+$ ion which acts as a transducer between thermal and spin reservoirs. Stimulated anti-Stokes Raman scattering between Zeeman sub-levels has previously been shown [3] to cool the ion below the Doppler limit. Raman transitions transfer the energy from the motional state by increasing the energy of the emitted photon with respect to the absorbed photon. This process can be stimulated with a second laser beam or the emitted photon can be scattered spontaneously. In the latter case the "work" photon whose energy has been increased can be distinguished from the background beam using sub-MHz precision spectroscopy. The process of reducing the motional quanta through the emission of a work photon increases the entropy in the atom's internal state, which can then be reset using either deterministic quantum gate operations or probabilistically through collisions with a suitable spin reservoir. This process is not a coherent spin exchange mechanism, so investigation into self-induced Zeeman coherence[4] could offer an alternative for resetting the ion's spin.

Experimentally, the vibrational modes rethermalise continuously under the influence of the surrounding environment and anharmonic trap interactions. As a first step in this project, we present measurements of the rethermalisation rate of the crystal's vibrational modes returning to a Maxwell-Boltzmann distribution after a single extraction, and the optimisation of Raman detunings and laser beam spot sizes to balance speed against fidelity.

[1] Jackson S. S. T. Wright. Physical Review A, 97:052104, 5 2018.

[2] Joan A. Vaccaro. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 467:1770–1778, 6 2011

[3] Jordan Scarabel, Frontiers in Optics + Laser Science 2021, JW7A.33

[4] H. Hard, Applied Physics B 131:137, volume 53, Issue 3, 1991