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Towards standing-wave quadrupole Mølmer-Sørensen gates

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Free-space optical lattices are ubiquitous in atomic physics and are often employed for creating spin-dependent forces used for entangling gate operations and neutral atom trapping. Recently, there has been an interest in gaining control over the absolute phase of the optical lattice [1] and harnessing it for applications in quantum metrology, quantum information processing with continuous variables [2] and quantum simulations [3]. Moreover, controlling this absolute phase enables complete control over all the degrees of freedom of the laser-ion interaction and hence allows for development of fast, high-fidelity entanglement schemes for trapped ions [4, 5].

Driving a quadrupole transition with a standing wave yields orthogonal coupling of the carrier and the sideband transitions depending on the position of the ion in the lattice [3, 6]. By controlling the phase of the optical lattice, ions can be placed at the antinodes of the standing wave where the coupling to the carrier is strongly suppressed while the motional coupling is maximised. Employing such a lattice for implementing a Mølmer-Sørensen (MS) gate scheme on multiple ions removes a dominant source of error in quadrupole gates: off-resonant excitation of the carrier. In our experiment, we are aiming to drive an MS gate using a standing wave instead of a travelling wave. This will allow us to implement high-fidelity gates in a regime where otherwise the unwanted excitation of the carrier would be a dominant error. The realisation of the carrier-nulled gate mechanism is a key step towards overcoming the current speed and fidelity limits on entangling gates in trapped ions, as described in more detail in the submission by S. Saner.

The free-space optical lattice is formed by two counter-propagating beams which couple the quadrupole transition, $5S_{1/2}, \leftrightarrow 4D_{5/2}$, in $^{88}Sr^{+}$. They make up an interferometer with the closing point at around 50 cm from the ion position, where the residual phase fluctuations are, after stabilisation, $\sim$0.02π rad. We then measure the lattice phase seen by the ion and adjust the interferometer lock point to compensate for any changes in the optical path length between the ion position and the closing point. We show coherent operations with the lattice for one and two ions and present progress towards implementing the MS gate using the standing wave on two ions.

References

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