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Entanglement growth and quench dynamics with trapped ions

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In recent years, a lot of progress has been made in exploring and understanding out of equilibrium dynamics of many-body quantum systems. This has been strongly motivated by the development of highly-controllable systems in experiments, where the microscopic parameters can be varied time-dependently and the resulting dynamics directly observed. One interesting feature that can be studied in this context is the behaviour of bipartite entanglement during such dynamics, which provides both insight into the underlying microscopic processes and information about the complexity of the resulting quantum states. A new set of possibilities for exploring both equilibrium and out of equilibrium dynamics has recently been provided by chains of trapped ions - in particular, the possibility to engineer spin models with a tunable range of spin-spin interactions along the chain. We explore the non-equilibrium coherent dynamics after a quantum quench in these systems, identifying qualitatively different behaviour as the exponent α of algebraically decaying spin-spin interactions in a transversing Ising chain is varied. Computing the build-up of bipartite entanglement as well as mutual information between distant spins, we show that interactions with $\alpha > 1$ lead to linear growth of bipartite entanglement in time, with the maximum rate of growth occurring when the Hamiltonian parameters match those for the quantum phase transition in this model. For $\alpha < 1$, the behaviour is qualitatively different, and for large parameter regimes, the growth of bipartite entanglement is counterintuitively only logarithmic, i.e., substantially slower than shorter range interactions. We show that these results are directly observable in experiments, and discuss the implications for the generation of large scale entanglement in these systems with a scaling that can render existing classical simulations inefficient.