Quantum states of trapped ions sensing fluctuation-induced phenomena

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Single trapped ions, and crystals of trapped ions, exhibit outstanding coherence times [1]. At the same time, quantum states of single trapped ions, and multi-ion entangled states can be prepared, manipulated and detected almost perfectly. Therefore, such "sensor" states present excellent preconditions for long, and controlled phase evolution and may be employed to detect various fluctuation-induced phenomena. For example, trapped ions allow for measuring electric field noise of nearby surfaces [2, 3]. Here, the electric field sensing relies on a very sensitive detection of the motional heating once an ion had been cooled before into its harmonic oscillator ground state. We have now reached a sensitivity of few phonons only per second. Alternatively, a novel electric field sensor is established using Rydberg excitations of a single ion [7], where the polarizability of states is higher by serveral orders of magnitude. As another example, single trapped ions serve to detect magnetic fields and their fluctuations, but entanglement-enhanced sensors using ion crystals show significant advantages and reach a sensitivity of 12 pT / $\sqrt{Hz}$ [5, 4]. So far, all sensing techniques have been limited to trapped ions inside the electrode structure of a Paul trap, thus with a quite limited range of technology and scientific applications. I will conclude by discussing the extraction of single ions out of the Paul trap, and focussing the beam into a nm-size focus [6], therefore opening quantum sensing for many future tasks where probes are placed outside the Paul trap.

But experiments with trapped ions do not only show excellent features to investigate fluctuation but also to employ such noise for driving heat engine cycles with trapped ions. Specifically, we have operated a single ion as a Otto motor [8]. Recently, we have realized experimenally a spin-driven heat engine with a single ion, where we operate fully in the quantum regime of the harmonic oscillator modes and observe the onset of motional excitation starting from the ground state. From a full state tomography we deduce the extracted mechanical work. Quantum spin fluctuations are revelant for understanding the operation of the machine and its efficiency. I will outline future plans where entropy in injected via ancilla ions to process multi-ion quantum engines.

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