A Single-Ion Heat Engine in the Quantum Regime

Ulrich Poschinger, QUANTUM, Universität Mainz

Our group has previously demonstrated the operation of a heat engine, where the working medium consists of a single trapped ion\(^1\). Here, we present current work with the aim of realizing a similar engine operating in the quantum domain. For this approach, the working medium is the spin degree of freedom of a single trapped \(^{40}\text{Ca}^+\) ion. This ion is positioned in a phase-stable standing optical wave\(^2\), which gives rise to a spin-dependent optical dipole force. This in turn provides coupling of the spin to the harmonic motion of the ion, which acts as a work repository.

The ion is subjected to alternating optical pumping pulses, synchronous to the frequency pertaining to its harmonic confinement. Therefore, the spin is alternating between two different polarizations, effectively corresponding to two temperatures. This gives rise to a resonant force mediated by the standing wave, which leads to the onset of oscillations of the ion position. The ion motion starts from the ground state and gains some tens of motional quanta during the engine operation. We characterize the state of work repository in terms of mean energy and energy fluctuations throughout the engine operation by recording Rabi oscillations. We find that the energy fluctuations are close to the fundamental limit imposed by the randomness of the optical pumping. By complementary measurements of the Husimi-Kano Q-function of the ion motion, we additionally reveal phase fluctuations of the oscillations.

We present measurements of the increase of both oscillatory and thermal energy stored in the ion motion during the onset process, and we discuss in how far the thermal energy is caused by fundamental work fluctuations. Furthermore, we discuss prospects for achieving limit-cycle operation or autonomous operation of this engine.

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\(^1\) J. Roßnagel et al., Science 352, 325 (2016)