Quantum probes and quantum engines realized via individual impurities immersed in an ultracold bath.

Artur Widera

Technische Universität Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern, Germany

Technological advances in laser and vacuum technology have allowed realizing a dream of the early days of quantum mechanics: controlling single, laser-cooled atoms at a quantum level. Interfacing individual atoms with ultracold gases offer new experimental approaches to study fascinating phenomena of nonequilibrium quantum physics. Moreover, such systems allow experimentally addressing the question if and how quantum properties can boost the performance of atomic-scale devices.

In this talk, I will discuss how single atoms can be controlled and probed in an ultracold gas to establish new paradigms of sensing temperature or operating nanoscale engines. Understanding the impurity-gas interaction at the atomic level allows employing inelastic spin-exchange collisions, which are usually considered harmful, for quantum applications. First, I will show how the inelastic spin-exchange can map information about the gas temperature or the surrounding magnetic field to the quantum-spin distribution of single impurity atoms. Interestingly, the nonequilibrium spin dynamics before reaching the steady-state increases the sensitivity of the probe while reducing the perturbation of the gas compared to the steady-state. Second, I will discuss how the quantized energy transfer during inelastic collisions allows operating a single-atom quantum engine. We overcome the limitations imposed by using thermal states and run a quantum-enhanced Otto cycle operating at orders of magnitude larger powers compared to a thermal case, alternating between positive and negative temperature regimes at maximum efficiency. I will discuss the properties of the engine as well as limitations originating from the quantum aspects resulting in fluctuations of power. Finally, I will show that single atoms can act as coherent probes for an ultracold gas, where both the interaction-driven coherent evolution of a quantum superposition and the collisional decay of coherence allow inferring information about gas properties. Our work opens the door to experimentally interface quantum physics and thermodynamics and to study emerging novel phenomena.