Realization of an Optical Interface Between a Trapped Ion and a Levitated Nanoparticle

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Hybrid quantum systems combining trapped ions and levitated nanoparticles offer complementary advantages: ions provide exceptional quantum control, long coherence times, and efficient optical readout, while nanoparticles enable quantum experiments with a large mass, strong optomechanical coupling, and force sensitivity. Interfacing these systems opens new possibilities for quantum sensing, test of fundamental physics, and experiments at the quantum to classical boundary with unprecedentedly large particles.

We present the development of an optical interface between an optically levitated nanoparticle and a single ion confined in a Paul trap. Our setup employs two independent traps in separate vacuum chambers, which are optically coupled. This architecture allows independent optimization of trapping conditions while reducing motional decoherence. The interface is based on a Mach–Zehnder-like interferometric configuration, where both systems are illuminated by laser light frequency-locked near the Ba^+ $6S_{1/2} \leftrightarrow 6P_{1/2}$ transition at 493 nm. The nanoparticle acts as a mirror inducing a position dependent phase offset, while the ion functions effectively as a beam splitter.

The interface quality is characterized by the spatial overlap of the scattered optical fields, quantified via the measurement of the second-order photon correlations. In the bulk coupling and detection setups, we measure the normalized second-order correlation function at zero time delay, achieving $g^{(2)}(\tau = 0) = 0.93 \pm 0.06$ for the optimized spatially overlapped coupling. This indicates a mode overlap of 0.37 ± 0.14, which is consistent with the theory for our settings. We further demonstrate motional driving of the ion by light scattered off the nanoparticle. Presented experimental achievements, together with the feasibility of the phase locking of this interferometric interface, promise observation of the nanoparticle position-dependent optically mediated force on the trapped atomic ion. This can be measured with very high accuracy using a co-trapped Ca^+ ion in our setup.

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