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Quantum electromechanics with levitated charged particles

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Controlling the motion of levitated nanoscale objects in the quantum regime is a challenging task with great relevance to sensing applications, quantum technologies, and fundamental physics. In this talk I present a theoretical framework to establish quantum electromechanics with levitated charged particles as a viable all-electrical approach to achieve such quantum control. Three main aspects are discussed. (i) I derive the effective potential describing how the position and orientation of a large nanoparticle with a rigidly bound charge distribution are confined by the rapidly oscillating electric field of a Paul trap. The levitated object can be coupled to electric circuitry through image currents induced in nearby pick-up electrodes. I determine this coupling and show that circuits with resistive elements allow one to slow down efficiently the translational and rotational motion in the trap. (ii) Interfacing the nanoparticle with a Cooper-pair box -- a superconducting circuit with pronounced quantum features -- enables to generate non-classical motional states. I present a rapid sequence of circuit manipulations that produces and verifies nanoparticle quantum interference in a realistic setup. (iii) I assess to what extent electric-field noise originating from nearby electrode surfaces disturbs the coherent quantum dynamics. Applicable to levitated particles with arbitrary charge distribution and to surfaces with general material properties, the associated Lindblad master equations can help to mitigate surface-induced decoherence in a wide range of state-of-the-art and future quantum experiments.