Measurement and Control of Individual Quanta in Cavity QED

Thesis by

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Because we know it, we are not an accident:
chance, redeemed returns to order.
Tied to the earth and to time,
a light and weightless ether,
thought supports the worlds and their weight.

– *Response and Reconciliation*, Octavio Paz

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Abstract

Cavity quantum electrodynamics (QED) in the strong-coupling regime provides the opportunity to monitor and control the dynamics of a simple quantum system. A single Cesium atom interacts strongly with single-photon fields in the mode of a high-finesse optical cavity. When the resulting coherent coupling rate dominates dissipation in the system, strong coupling is realized and the system displays distinctively quantum behavior. The coupling between atomic internal states and the quantized cavity field allows for diverse protocols in quantum state preparation, quantum communication, and quantum logic. However, the atom's external or motional state must also be taken into account. My research develops cavity QED in the limit where the coherent atom-field coupling dominates the atomic kinetic energy and thus significantly affects the atomic center-of-mass motion. In this regime, the interaction of the atom with the cavity field provides both a means of controlling atomic motion and a signal for detecting that motion in real time with high signal-to-noise. The sensing capability of the "atom-cavity microscope" is exploited to trap single atoms with single-photon fields and to monitor their orbits in real time as they are bound in the cavity. Such real-time position sensing is the basis for a detailed strategy and ongoing experiment to actively stabilize select aspects of an atom's motion within the cavity. As the cavity-enabled position measurement approaches the standard quantum limit, this work begins to realize a quantum servo for atomic position and to address questions of optimal state estimation and state preparation. In combination with other progress in cavity QED, it furthers the goal of controlled atom-field interactions for quantum information science.

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