Full observation of single-atom dynamics in cavity QED

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Abstract

Optical cavity quantum electrodynamics (QED) in the strong coupling regime provides a unique experimental paradigm for real-time observation of quantum dynamical processes at the single-atom level. In this talk, I will describe recent experimental work in which we used broadband heterodyne spectroscopy to record the complete time-evolution of interaction energy between one atom and a high-finesse cavity during individual "scattering" events of $\sim 250\ \mu s$ duration. The instantaneous value of this energy depends on both the atomic position and (Zeeman) internal state, with variations in time caused predominantly by atomic motion through the spatial structure of the cavity eigenmode. Our measurements have been conducted in a regime of strong but dispersive atom-cavity coupling, ensuring that dynamical variations of the interaction energy remain within the detection bandwidth. With characteristic atom-cavity interaction energies $E_{int}/\hbar \sim 10$ MHz, we achieve a shot-noise-limited measurement sensitivity $\simeq 3$ kHz/$\sqrt{\text{Hz}}$ over a bandwidth that covers the dominant rates of variation in E_{int}. By surpressing all sources of excess technical noise, we have begun to approach a measurement regime in which the broadband photocurrent may be interpreted as a classical record of *conditional* quantum evolution. This represents a fundamental prerequisite for experimental realization of manifestly quantum-mechanical feedback control in any open dynamical system.