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Single atoms in optical traps and high-Q cavities

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RESEARCH PROGRAMS

A variety of experiments are underway in the Quantum Optics Group at Caltech which investigate the quantum nature of atom-field interactions at the level of individual atoms and quanta.[1] A recent technical advance in support of this research is the observation of cooling and trapping of single neutral Cesium atoms in a magneto-optical trap[2]. Discrete steps are recorded in the fluorescence signal from the trap and are associated with the arrival and departure of individual trapped atoms. Such a spatially localized sample of a single atom with small kinetic energy is an enabling advance for diverse studies in quantum optics, including the possibility of spectroscopy with squeezed and other forms of nonclassical light[3] and cavity quantum electrodynamics with strong coupling of an atom to the field of an optical cavity [4].

With regard to this latter area, we have recently achieved a system that approximates a "one-dimensional" atom[5]. That is, coherent coupling (to the Gaussian mode of a Fabry-Perot cavity) dominates incoherent atomic emission (into free space). In terms of the often quoted ß parameter, we have demonstrated ß = 0.7 for the ratio of emission into the cavity mode as compared to the total atomic decay rate. A novel feature revealed by our direct spectroscopic measurements of the atom-cavity system is that saturation occurs for only 0.02 intracavity photons.

Apart from applications in quantum optics, we would like to stress the possibilities for enhanced single-atom detection provided by the strong atom-field coupling. The in principle gain in sensitivity for detection of an atom in free space as compared to an atom in a cavity such as ours goes as the magnitude of the mirror losses. Note that we have previously observed mirror losses as small as 1.6×10^{-6}, corresponding to finesse of 1.9×10^{6} [6], so that there is considerable potential for dramatic improvements in single-atom detection capabilities. Beyond issues of principle is the practical advantage that the Gaussian-mode of the atom-cavity SYSTEM can be probed with near unity overall efficiency as compared to the much lower detection efficiencies for free-space absorption or fluorescence measurements.

Other areas of investigation that make use of tools such as the control of single-atom trajectories and atom-cavity interactions with strong coupling are our recent proposals involving the coupling of individual atoms to the whispering gallery modes

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of quartz microspheres. We have analyzed the prospects for quantum nondemolition measurements of the photon number of the intracavity field[7] and indeed for binding atoms in stable orbits around the microsphere[8]. A final topic to mention in this regard is the possibility for the synthesis of arbitrary quantum states of the electromagnetic field [9].

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3. REFERENCES

1. "Quatum Optics With Strong Coupling", H. J. Kimble, O. Carnal, N. Georgiades, H. Mabuchi, E. S. Polzik, R. J. Thompson, and Q. A. Turchette, in Atomic Physics 14, eds. D. J. Wineland, C. E. Wieman, and S. J. Smith (American Institute of Physics, Woodbury, New York, 1995), 314.

2. "Observation of a Single Neutral Atom in a Magneto-Optical Trap", Z. Hu and H. J. Kimble, Optics Letters 19, 1888 (1994).

3. "Spectroscopy with Nonclassical Light", H.J. Kimble, E.S. Polzik, N. Georgiades, and H. Mabuchi, in Laser Spectroscopy XIth Intl. Conf., eds. L. Bloomfield, T. Gallagher, and D. Laser, (American Institute of Physics, Woodbury, New York, 1994) 340.

4. "Structure and Dynamics in Cavity Quantum Electrodynamics," H. J. Kimble, in Cavity Quantum Electrodynamics, Advances in Atomic, Molecular, and Optical Physics, ed. Paul Berman (Academic Press, Inc., 1993).

5. "One-Dimensional Atoms", Q. A. Turchette, R. J. Thompson, and H. J. Kimble, App. Phys. B (1995).

6. "Measurement of Ultralow Losses in an Optical Interferometer," G. Rempe, R. J. Thompson, H. J. Kimble, and R. Lalezari, Opt. Lett. 17, 363 (1992).

7. "Quantum Nondemolition Detection of Single Photons in an Open Resonator by Atomic Beam Deflection", A. B. Matsko, S. P. Vyatchanin, H. Mabuchi, and H. J. Kimble, Phys. Lett. A 192, 175 (1994).

8. "Synthesis of Quantum States via Adiabatic Transfer of Zeeman Coherence", A. S. Parkins, P. Marte, P. Zoller, and H. J. Kimble, Phys. Rev. Lett. 71, 3095 (1993).

9. "Atom Galleries for Whispering Atoms: Binding Atoms in Stable Orbits Around an Optical Resonator", H. Mabuchi and H.J. Kimble, Opt. Lett. 19, 749 (1994).