캐비티-유도된 원자측정장치

A Cavity-Assisted Atom Detector (CAAD)

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We introduce a scheme with a maximized efficiency of detecting atoms passing through an optical standing-wave mode cavity. Consider a standing-wave optical cavity illuminated by a weak probe beam through one of its mirrors where the transmission through the other mirror is monitored by a photodetector. If an atom is put in the cavity, the atom-cavity coupling shifts the resonance frequency of the system via the so-called normal mode splitting, and thereby the transmission power will drop. In fact, this type of atom detection scheme has been used in recent single atom trap experiments In practice, however, the field in a standing-wave mode will have a geometrical structure having nodes and antinodes that when the atom traverses the cavity through one of the nodes, there will be no such effect of atom-field interaction. Such non-uniform coupling has been a fundamental problem in a standing-wave cavity in the optical regime and a scheme to achieve a uniform coupling is therefore highly desired. In this work, we suggest an extremely simple but essential resolution to the problem. That is none other than a crooked incidence of atomic beam from the normal to the cavity axis. When the atomic beam is tilted, the atoms will see two counter-propagating planar traveling waves with Doppler-shifted frequencies rather than one single standing wave. When the system is prepared so that the frequency of one of the traveling waves is resonant with the atomic frequency, the atom will essentially interact with only the wave that has no geometrical structure, given that the Doppler shift is sufficiently large, and will show a position-independent uniform coupling. We show numerically this interesting phenomenon through the quantum trajectory simulation where the atomic as well as the cavity damping effects are fully taken into account. When an atom comes into the cavity, the dynamics of the system consists of the piecewise continuous evolution – described by a Schroedinger-like equation with the non-Hermitian Hamiltonian H such that $H/i\hbar = -i(1/2\,\omega_A\sigma_{Z-i}\omega_C a^{\dagger} a + g(\vec{x})(\sigma_- a^{\dagger} - \sigma_+ a) + E(ae^{i\omega_L t} - a^{\dagger} e^{-i\omega_L t}) \quad - \kappa a^{\dagger} a - (\gamma/2)\sigma_+\sigma_-$ where E denotes the probe beam intensity, 2κ and γ, the cavity and the atomic decay rate, respectively, while the position-dependent atom-cavity coupling is given by $g(\vec{x}) = g_0 \cos(kx) \exp\{-(y^2+z^2)/2w^2\}$ with $k = 2\pi/\lambda$, the wave- number of the field, and w, the beam-waist – accompanied by the quantum jumps such that $|\psi\rangle \rightarrow a|\psi\rangle$ when $2\kappa dt\langle a^{\dagger} a\rangle \geq R_1 \in [0,1)$ and $|\psi\rangle \rightarrow \sigma_-|\psi\rangle$ when $\gamma dt\langle \sigma_+ \sigma_- \rangle \geq R_2 \in [0,1)$. Figs. 1 and 2 show the temporal behaviors of the intracavity photon number so obtained. Note that the intracavity

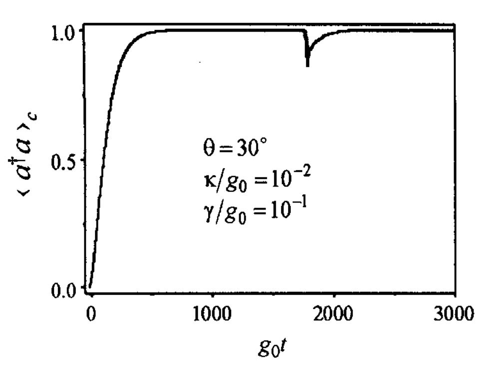

Fig. 1 Temporal behavior of intracavity photon number with atom beam incidence of 30° from the normal to the cavity axis, for $\omega_C = \omega_L = \omega_A$.

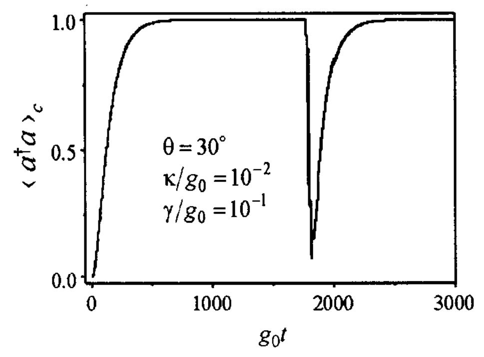

Fig. 2 For $\omega_C = \omega_L = \omega_A \pm kv_x$.

photon number is proportional to the transmission power from the cavity. In both figures., the atomic beam is tilted by 30° from the normal incidence and the initial atomic velocity $\vec{v} = (g_0\lambda, 0, 0)$ with $w = 10\lambda$. Fig. 1 shows the case of full resonance, i. e., $\omega_C = \omega_L = \omega_A$ while Fig. 2 is the case where the cavity and the probe beam frequencies are tuned to compensate for the Doppler shift due to the atomic motion along the cavity axis so that $\omega_C = \omega_L = \omega_A \pm kv_x$. A striking drop in the intracavity photon number is observed in the latter figure at the time of the atomic passage through the cavity. We will also show that a more realistic model in which the effect of the position and momentum quantization are included will reveal no essential difference from this simple model. We believe that the techniques utilizing this simple detection scheme will provide an effective way out of the difficulty arising from the non-uniform atom-cavity coupling in the optical regime.

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Reference

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