단일 모드 공진기에서의 동역학 공명형광
Dynamic Resonance Fluorescence in a Colored Vacuum

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Resonance fluorescence is the manifestation of the interaction between the physical system under consideration and the vacuum-field fluctuation. The fluorescence spectrum provides such physical informations as the energy-level structure of the system, instabilities and relative populations of the energy levels, etc.. One of the typical fluorescence spectra is the Mollow triplet appearing when two-level atoms are driven by a strong coherent field in free space(1) . In the weak field limit, the singlet instead of the triplet is obtained with a reduced linewidth due to the squeezing of one quadrature phase of the induced atomic dipole(2). On the other hand, when the atoms are put inside a cavity rather than in free space, a doublet spectrum due to the vacuum Rabi-splitting is achieved, showing clearly the coupling of atoms and the cavity in the single-quantum limit(3). Especially, Carmichael et al. (4) predicted theoretically that (1) the doublet spectrum could be narrowed by the linewidth averaging in the spontaneous emission case and (2) more narrowed linewidths would be observed by squeezing as well as averaging when the cavity is weakly driven. The normal-mode splitting and the linewidth reduction due to the strong atom-cavity coupling have been observed in the transmission spectra in the weak driving-field limit(5). The splitting for one atom on average has been investigated by Thompson et. al(6). These experiments were, however, incomplete in the sense that the spectra were averaged over many atoms. A true single atom experiment is yet to be performed related to the recent progress in the single atom trapping in a cavity (7). It should be noted that the mode variation inside cavity often diminishes the expected single atom effect (8).

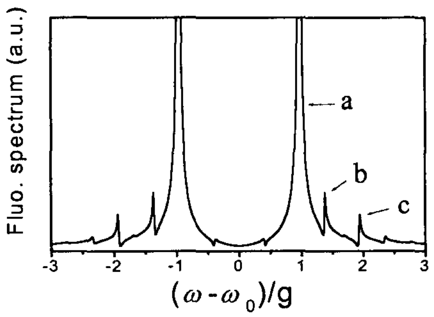
As might be hinted by the above experiment, in order to observe the interaction of the cavity and the atoms (e.g. vacuum Rabi-splitting), they have driven the Jaynes-Cummings system by weak external field which acted as a probe not deforming the system. But, what will be the fluorescence spectrum (FS) if the driving field is strong enough to change the Jaynes-Cummings Ladder (JCL), the level structure of the Jaynes-Cummings system? A naive expectation is that the high lying states in the JCL would be excited and transitions between adjacent levels contribute to FS.

In this research we show that it is not the case and anomalous resonances appear which cannot be explained in terms of the JCL structure. We will explain the origin of all the anomalous peaks in the FS. We study the fluorescence spectra with arbitrary driving-field strength not confined to the weak-field limit. Carmicheal et al.(9) calculated the FS in the same system as ours and showed that the spectra are very similar to those in the case of an atom moving inside the standing wave mode of cavity without external driving. But contents and physical meanings are completely different in this research. The frequencies of fluorescent photons in the Jaynes-Cummings system are given by $\omega_0 \pm (\sqrt{n+1} \pm \sqrt{n})\,g$ ($n \geq 0$; integer) since the usual transition is only between the neighboring manifolds. We show that in the strong-coupling limit there can be the transitions from manifold-n to manifold-(n minus m) ($m \geq 2$) due to the dynamic Stark effect, which is quite contrary to our usual notion of fluorescence. They are not from the multi-photon processes. We discuss how these new types of resonances can occur.

In our model a single-mode cavity, resonantly coupled with a two-level atom, is driven by a classical field of arbitrary-strength as described by a Hamiltonian

$$H = 1/2\,\hbar\,\omega_A\sigma_z + \hbar\,\omega_c a^+ a + i\hbar\,g(a^+\sigma_- - a\sigma_+) + i\hbar\,\varepsilon(a^+ e^{-i\omega_L t} - a\,e^{i\omega_L t}),$$

where $\omega_A, \omega_c, \omega_L$ are the atomic transition, the cavity resonance, the driving-field frequency respectively. And g is the atom-cavity coupling strength, ε the coupling strength of the driving field and the cavity proportional to the driving-field amplitude. In the figure below, we show the fluorescence spectrum in case of strong atom-cavity coupling ($\gamma = 2\kappa \ll g$, γ : atomic damping, κ : cavity loss) and $2\varepsilon/g = 0.2$. The peak (a) corresponds to the modified vacuum Rabi splitting and the position is at $\pm g[1-(2\varepsilon/g)^2]^{(3/4)} \equiv \pm g'$. The peaks (b) and (c) are anomalous which cannot be explained with the usual concept. The peak (b) is at $\sqrt{2}\,g'$ and the peak (c) $2g'$. So they are not from the transitions between neighboring manifolds.



We will also discuss the fluorescence spectra and the transmission spectra in case of intermediate damping.

This work is supported by Creative Research Initiatives of the Korean Ministry of Science and Technology.

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