Collective spontaneous emission for many atoms

beyond the rotating-wave approximation

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Abstract: We study the collective spontaneous emission of \( N \) multilevel atoms in optical vector theory and without applying the rotating-wave approximation.

The phenomena of spontaneous emission and Lamb shift in atomic systems are two of the most intriguing effects in quantum optics [1]. In most theoretical studies, the rotating-wave approximation (RWA) is applied to simplify the atomic system as a two-level one, as counter-rotating contributions leading to virtual processes related to higher levels are neglected. Recently, people [2] discussed the collective spontaneous emission of \( N \) two-level atoms with the counter-rotating terms included and found that the virtual processes from the counter-rotating terms could induce non-negligible effects in the long-time cooperative spontaneous emission.

Here, we [3] study the collective spontaneous emission of \( N \) multilevel atoms in optical vector theory including all possible wave-vector directions and polarizations of the vacuum modes. The effects of counter rotating terms are included by applying a unitary transformation method, which gives an effective Hamiltonian with the similar form to that in RWA.

The time-dependent population and cooperative decay rates for two initial states (the standard Dicke and timed Dicke states) are calculated numerically. We find both the initial states form approximately exponentially decaying eigenstates for small volumes. But for intermediate volumes, they are not eigenstates of the ensemble, resulting in complex time evolutions. We also consider the effect of the ensemble geometry on the cooperative emission.

Fig. 1. (Left) The dynamic evolution of the total upper-state population and (Right) the corresponding effective decay rates, with fixed \( N = 8000 \) atoms in a sphere with radius \( R = 12\lambda, R = 6\lambda, \) or \( R = 3\lambda \).

(iii) Here the initial state is the timed Dicke state.

References: