Quantum Engineering of Superdark Excited States in Arrays of Interacting Atoms

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There is growing interest in subwavelength atomic ensembles with an enhanced radiative lifetime of collective excitations. Several configurations of one- and two-dimensional (1D and 2D) atomic arrays have been proposed (see, *e.g.*, [1,2] and refs. therein) that show substantial decrease of the decay rate as compared to that of an individual atom. For two atoms, a few schemes for controlling sub-radiant states in 1D [3-5] and in 3D [6] were suggested. The suppression of the radiative decay is caused by destructive interference of emission amplitudes of different members of the atomic ensemble. This effect is most pronounced in the seminal Dicke model of a compact ensemble of N identical two-level atoms without non-retarded dipole-dipole interaction: one of the singly excited collective states is super-radiant while the other $N-1$ singly excited states are non-radiant at all. The presence of the dipole-dipole interaction leads to formation of the eigenstates ('excitons') of the atomic ensemble which may reveal the properties of super- and sub-radiation. In small- size ensembles, the resonant dipole-dipole excitation transfer is the strongest effect, while the spontaneous radiative decay occurs due to a weaker interaction with the transverse quantum electromagnetic field. Both the exciton states and their radiative decay rates are determined by the geometry of the atomic array. The search for an array geometry with a minimal decay rate seems to be the matter of art. Recently we have suggested [7] a method to achieve an extremely long lifetime of an excited collective state in a generic small-size array of N atoms. The decay rate Γ_N of such a "superdark" state can be as small as $\Gamma_N \propto \Gamma(r/\lambda)^{2(N-1)}$, where Γ is the radiative decay rate of an individual atom, and r and λ are the system size and the resonant wavelength of the atomic transition, respectively. The method is based on a special fine-tuning of the exciton Hamiltonian. The control parameters are properly adjusted atomic transition frequencies. Their fine tuning can be achieved by auxiliary laser fields. We have calculated necessary atomic frequency shifts to reach the optimal configuration. Extreme sensitivity of the slow spontaneous decay rate and the narrow radiative width to external fields may be useful for precision measurements in fundamental research.

References

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