Radiative Coupling of a Multilevel Atom with a Dielectric Structure

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The coupling of quantum emitters, such as cold atoms, with nanoscale structures like dielectric waveguides and subwavelength resonators brings new opportunities for quantum technology. The directional emission of individual photons could create certain conditions for a quantum computer interface based on neutral atoms. Prototypes of similar nanophotonic devices have been already demonstrated in experiments involving the confinement of atoms within microresonators, photonic crystal structures, and nanofibers [1].

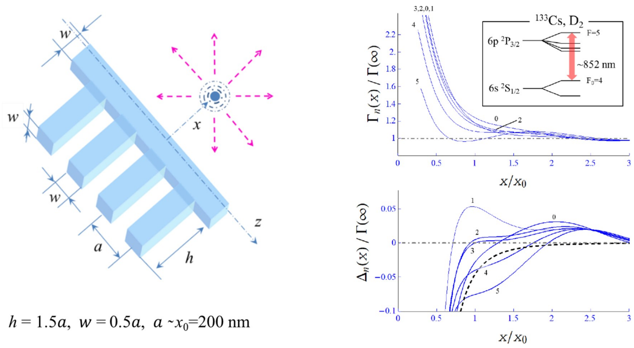

Figure 1: Radiation decay rates and radiative shifts, calculated for quasi-energy states formed by radiation from an isolated transition of the caesium-133 atom placed near the one-dimensional asymmetric photonic crystal (InGaP)

We propose a microscopic scheme for calculating radiation corrections to the energy spectrum of a single-electron atom in the presence of a nanoscale dielectric object. The calculation takes into account the complete Zeeman structure of an isolated atomic transition and can be applied to systems with arbitrary geometric configurations. At the studied frequencies, the dielectric properties can be replicated by replacing the bulk material with an ensemble of two-level atoms with resonant transition frequencies being offset from the radiation frequency of a reference atom [2].

We demonstrate the approach by applying it to various nanostructure geometries used in the experiments [3] and conduct a comparative analysis to demonstrate the advantages of exciting an atom at frequencies close to the edge of the Brillouin zone in asymmetric photonic crystals. Figure 1 demonstrates spectral parameters of the caesium-133 atom placed near the one-dimensional asymmetric photonic crystal. Quasi-energy sublevels exhibit twofold degeneracy and non-orthogonality between states from different energy levels, which we show is connected to the nontrivial axial symmetry in atomic excitation and decay channels.

The observed increase in atomic decay rate is accompanied by its directional radiation into a waveguide mode, which is significant for developing quantum interfaces based on individual atoms and photons. Due to this radiation, a resonant scattering channel can be used to create a chain of entangled atoms. The phase of the atomic state changes by 180 degrees during the resonant scattering of photons, that is a critical aspect of the C-Z entanglement protocol, a promising scheme proposed as an alternative to the Rydberg blockade protocol.

Acknowledgements: The work was funded by the Russian Science Foundation (Project No. 23-72-10012).

References

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