Photon and Spin Dependence of the Resonance Lines Shape in the Strong Coupling Regime

S. Miyashita (Univ. Tokyo), S. Bertaina (CNRS – Marseille), I. Chiorescu (NHMFL and FSU – Physics)

Introduction

We study the quantum dynamics of a spin ensemble coupled to cavity photons. Recently, related experimental results have been reported, showing the existence of the strong coupling regime in such systems. In the case of strong coupling regime, the spin system collectively exchange quanta of radiation with a resonant cavity containing the spins. Such regime can be used to store quantum information in long lived spin states and to process it via ESR-type pulsed operations. This work was published following an invitation by the *J. Phys. B: At. Mol. Opt. Phys* [1] which presented a special issue dedicated on Quantum Memories.

Experimental

This work mostly deals with simulations involving Hamiltonian diagonalization and its dynamics studied using a standard Lindblad type mechanism. The theoretical results are correlated with experimental evidence of the strong coupling regime, achieved with a spin 1/2 ensemble and measured at NHMFL.

Results and Discussion

We study the eigenenergy distribution of the multi-spin system (following the Tavis-Cummings model) which shows a peculiar structure as a function of the number of cavity photons and of spins (**Figure 1**). We study how this structure causes changes in the spectrum of the admittance in the linear response theory, and also the frequency dependence of the excited quantities in the stationary state under a probing field. In particular, we investigate how the structure of the higher excited energy levels changes the spectrum from a double-peak structure (the so-called vacuum field Rabi splitting) to a single peak structure. We also point out that the spin dynamics in the region of the double-peak structure corresponds to recent experiments using cavity ringing while in region of the single peak structure, it corresponds to the coherent Rabi oscillation in a driving electromagnetic field.

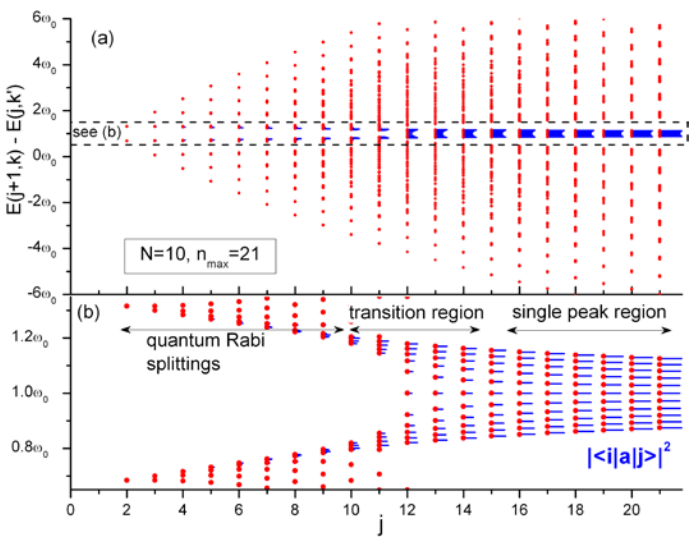

Figure 1. (a) Resonance frequencies as a function of the number of photons, for a coupled spin-photon system. Here, the number of spins is 10 and the max number of photons is 21. (b) a zoom of the region with resonances around the cavity resonance. The blue bars show the transition probability. When the number of photons exceeds the number of spins, the resonance gradually becomes a traditional, single peak, ESR-type resonance.

Conclusions

With our model, the role of other factors in the spread of Rabi splitting, such as: dipolar or hyperfine interactions, local anisotropic crystal fields, and the size of the sample vs. size of a cavity can also be studied. It is also interesting to study the relation between this dissipation effect and the existence of the optical bistability.

Acknowledgements

This work was partially supported by the Mitsubishi Foundation, the NSF Cooperative Agreement grant no DMR-0654118, and NSF Grant No. DMR-1206267, and also the Next Generation Super Computer Project, Nanoscience Program of MEXT. The computation in this work has been done using the facilities of the Supercomputer Center, Institute for Solid State Physics, University of Tokyo.

References

[1] Miyashita, S. *et al.*, J. Phys. B: At. Mol. Opt. Phys. **45,** 124010 (2012).