Cavity QED

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Abstract Light-matter interaction is often studied by focusing on the atomic part or the photon part only, with the other part being modeled as intermediate states (as in Maxwell's Equations in media), external sources (as in scattering theory), or a thermalized bath (as in quantum Langevin equation). For ultracold systems with strong light-matter coupling, none of the formalisms mentioned above works and both the atoms and the photons need to be modeled in a fully quantum and coherent way. In this report, we review cavity quantum electrodynamics (cavity QED or cQED), the theory of atoms interacting with photons within a reflective cavity. We will study how cQED reduces to aforementioned formalisms and discuss several phenomena that can only be reliably captured in cQED, including tunable and even reversible spontaneous emission, strong-field dressing effects, and the collapse and revival of the probability for the atom to appear in the excited state with the initial photon state being a coherent state. We will also discuss non-conventional experimental platforms, like excitonic materials in a cavity, for which cQED is a good effective theory.

Outline

- Basic formalism [1]
- Collapse and revival [4]
- Tuning spontaneous emission [4]
- Strong-field dressing effects [2]
- cQED in excitons [3]

References

[1] Matteo Bina. "The coherent interaction between matter and radiation: A tutorial on the Jaynes-Cummings model". In: *The European Physical Journal Special Topics* 203.1 (2012), pp. 163–183.

[2] Omar Di Stefano et al. "Cutting Feynman loops in ultrastrong cavity QED: Stimulated emission and reabsorption of virtual particles dressing a physical excitation". In: *arXiv preprint arXiv:1603.04984* (2016).

[3] Simone Latini et al. "Cavity control of excitons in two-dimensional materials". In: *Nano letters* 19.6 (2019), pp. 3473–3479.

[4] P Meystre. *Quantum Optics. Graduate Texts in Physics.* See chap. 7 for discussion on cQED. Springer Nature, 2021.