From superradiant criticality to solidification – fundamental limitation of ultrastrong coupling between light and atoms

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Abstract

We present a solution to the half-a-century old A-square problem of cavity quantum electrodynamics.

We present a solution to the long-standing problem whether the superrandiant (Dicke) phase-transition critical point can be reached in the original setting of the Dicke model: electric dipoles (atoms) in the electromagnetic field. For this we have to revisit some fundamentals of the modeling of light-matter interaction. First, by a generalization and modification of the Power–Zienau–Woolley (PZW) picture, we build such a framework for the quantum electrodynamics (QED) of atoms as is free from the A-square and P-square problems, and valid in arbitrary confined geometries [1, 2]. Second, by using this framework, we give an upper bound for the achievable coupling strength between light and atoms in the ultrastrong regime [2]. Supported by a scaling argument valid in the presented QED picture, we argue that the superradiant phase transition is a silhouette of a mundane phase transition, namely, solidification [2]. Third, we study the effect of the remainder of instantaneous atom-atom (depolarizing) interaction on the phase transition, finding a shift of the critical point from the pure Dicke one [3].

Finally, in connection with an ongoing theoretical debate [4], we present some insights on the relation between gauge transformations and the PZW picture, and point out an important freedom in the choice of canonical field momenta in nonrelativistic quantum electrodynamics

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