Regimes of cavity-QED under incoherent excitation: From weak to deep strong coupling

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The prototypical system constituted by a two-level atom interacting with a quantized single-mode electromagnetic field is described by the quantum Rabi model (QRM). The QRM is potentially valid at any light-matter interaction regime, ranging from the weak (where the decay rates exceeds the coupling rate) to the deep strong coupling (where the interaction rate exceeds the bare transition frequencies of the subsystems). However, when reaching the ultrastrong coupling regime, several theoretical issues may prevent the correct description of the observable dynamics of such a system: (i) the standard quantum optics master equation fails to correctly describe the interaction of this system with the reservoirs; (ii) the correct output photon rate is no longer proportional to the intracavity photon number; and (iii) they appears to violate gauge invariance. Here, we study the photon flux emission rate of this system under the incoherent excitation of the two-level atom for any light-matter interaction strength, and consider different effective temperatures. The dependence of the emission spectra on the coupling strength is the result of the interplay between energy levels, matrix elements of the observables, and the density of states of the reservoirs. Within this approach, we also study the occurence of light-matter decoupling in the deep strong coupling regime, and show how all of the obtained results are gauge invariant.