

Quantum-Emitter Dynamics near Dispersive Dielectrics in the Modified Langevin Noise Formalism

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Abstract: We model a quantum emitter near a finite dispersive dielectric in unbounded space, deriving medium- and scattering-assisted spectral densities, a temperature-dependent effective reservoir, and we study the nonperturbative nonequilibrium dynamics for a homogeneous dielectric sphere.

Harnessing the interaction between electromagnetic fields and matter is of growing importance across diverse areas of physics, from condensed matter physics to quantum optics and information. In this work, we model the interaction of a quantum emitter with a finite-size dispersive dielectric object in an unbounded space within the framework of macroscopic quantum electrodynamics [1-2], using the modified Langevin noise formalism [3]. The quantized electromagnetic field consists of two contributions: the medium-assisted field, which accounts for the electromagnetic field generated by the noise polarization currents of the dielectric, and the scattering-assisted field, which takes into account the electromagnetic field incoming from infinity and scattered by the dielectric. We show that the emitter couples with two distinct bosonic baths: a medium-assisted bath and a scattering-assisted bath, each characterized by its spectral density [4]. Therefore, for initial thermal states of the reservoirs having different temperatures, the common approach based on the dyadic Green function of the dielectric object cannot be employed. We study the interaction of a quantum emitter with these two reservoirs introducing a temperature-dependent effective spectral density of the electromagnetic environment, focusing on the case of a homogeneous dielectric sphere [5, 6]. We evaluate analytically the medium-assisted and the scattering-assisted spectral densities of a homogeneous dielectric sphere. We then show that the action of the two baths can be equivalently described by a zero-temperature bosonic reservoir with an effective spectral density given by the sum of the temperature-dependent medium-assisted and scattering-assisted spectral densities. Then, exploiting this equivalence, we study the time evolution of a two-level quantum emitter coupled to a dielectric sphere for dispersive electromagnetic environments out of equilibrium using a non-perturbative approach.

References

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