# **Atom-Field-Medium Interaction: A unified theoretical framework** for fluctuation forces, quantum friction, and quantum optomechanics

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## Abstract

We present a unified theoretical framework for studying the interaction between an atom or a mirror with a dielectric medium via a quantum field [1]. The range of problems covered includes a) the traditional atom-quantum field interaction in cavity QED, b) the mirror–quantum field interactions as in the Casimir and dynamical Casimir effects, c) the atom-medium forces, such as the Casimir-Polder force, and for moving atoms in the vacuum, the Unruh-Davies effect [2] and near a dielectric plane, the quantum friction forces. We construct a model of the medium with a harmonic lattice, and allow the atom/mirror to have both external and internal dynamical degrees of freedom (dof) [3]. The atom/mirror and dielectric slabs in a cavity field are the essential components in a typical setup in optomechanics. A problem studied recently with this model is that of atom-field entanglement in quantum optomechanics [4]. Here we use the influence functional formalism of quantum open systems to handle the interplay of these five dynamic variables. We perform graded coarse-grainings [5,6] to first obtain the effects of the dielectric on the quantum field and then the effects of the modified quantum field on the atom or mirror's internal degree of freedom. We show the advantages of a) using the Green function obtained from coarse-graining the dielectric dof *over* the existent macroscopic and stochastic electrodynamics approaches and b) deriving the equations of motion for the atom/mirror from the influence actions, for fully nonequilibrium conditions, *over* the linear response theory approaches valid only for near-equilibrium conditions. In this talk we describe the key procedures in our framework and report on the results from the first two papers where we treat a static atom (freezing the center of mass motion), in three aspects: spontaneous emission, spatial decoherence and atom-field entanglement. Our next stage of work will treat a moving atom first in a prescribed trajectory for motional decoherence [7] and entanglement, and then include back-action effects [8] for the treatment of quantum friction. Memory (nonMarkovian) effects are naturally included in all of these processes because this approach guarantees self-consistency in the dynamics of all relevant physical variables.

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