

# Vacuum-field-induced state mixing

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**Diego Fernandez de la Pradilla Viso**

Esteban Moreno, Johannes Feist

*Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain*

[diego.fernandez@uam.es](mailto:diego.fernandez@uam.es)

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The interaction of an atom with the electromagnetic environment supported by a macroscopic body induces both spontaneous emission and Casimir-Polder energy shifts of the atomic levels, offering control of atomic properties by tuning the parameters of the macroscopic body [1]. Typically, environmental effects are studied for individual atomic levels. However, for sets of near-degenerate states, the induced shifts can become comparable to the energy differences between levels, and it becomes necessary to treat an environment-induced interaction between the levels, which leads to off-diagonal terms in the decay and energy shifts induced by the field. In this study, we propose a method to describe such systems and show that the behavior of an atom near a macroscopic structure can differ significantly from the predictions of the conventional diagonal formulation of the theory. Our methodology is based on macroscopic quantum electrodynamics [2], along with a recently developed Lindblad master equation formalism that can handle near-degenerate levels and avoids some of the issues associated with the Bloch-Redfield equation and secular approximation [3]. This method includes both the well-known Casimir-Polder potentials in the diagonal energy shifts and the off-diagonal couplings. Due to them, the effective atomic eigenstates are linear combinations of the free-space eigenstates, which has physical consequences on, for instance, the atomic decay rates. We have simulated the fine structure of a hydrogen atom coupled to a dielectric nanoparticle and quantify the amount of Casimir-Polder-induced mixing of the eigenstates through

the so-called participation ratio. We also gauge the impact of the off-diagonal terms on the dynamics by extracting the eigenenergies and decay rates from the master equation and studying them as a function of the atom-nanoparticle separation. Noticeably, avoided crossings become a new feature of the energy spectrum. As for the decay rates, the enhancement of the Purcell factor leads to the expectation of increasing decay rates for smaller separations. Our findings, however, show this to be wrong, as the mixings induced by the off-diagonal terms lead to the opposite effect within a given range of distances for a particular atomic state. Such effects are not present at all in traditional Casimir-Polder treatments lacking the off-diagonal terms and are necessary to include to properly understand the physics behind quantum applications.

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## References

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