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The dynamics of resonant particles inside a cavity: exploration by an exact Green's function formulation

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The mutual interaction of a resonant particle inside a cavity is an intriguing topic with applications in various fields, such as optics, quantum electrodynamics, and materials science. From the particle perspective, the interaction between the resonant particle, which may be a nanoparticle or a molecule, and the cavity can lead to a variety of phenomena, such as enhanced electromagnetic absorption on the particle, and fluorescence by the particle, just to name a few. However, in such a coupled system, the mutual interaction between the particle and the cavity can affect the electromagnetic properties of the cavity itself, leading to changes in the resonant frequency, quality factor, and the field distribution. Additionally, the problem can become more complex when considering the presence of multiple particles or the effect of particle clustering, leading to cooperative phenomena like plasmon coupling and collective modes.

To address this problem, various methods have been developed, ranging from approximate analytical models based on perturbation theory to full-wave simulations. While these methods provide some insights into the fundamental physics of the interaction, the former are limited for weak scattering particles, whereas the latter are computationally extensive and lack an understanding of the underlying physical mechanisms.

In this work, we introduce an analytically exact model for the interaction mechanism between the particle and the cavity. The particle is assumed to be small and with a dipolar response. Our approach allows computationally efficient calculation of the mutual resonance of single and multiple particles inside a cavity and the evaluation of the cooperative behavior of the system. The key point of the model is the exact extraction of the free space (self) term of the Green's function in the cavity. To that end we suggest a sequence of alternative Green's function representations [1], which we alternately subtract from each other.

Using this approach, we present the dynamics of particles with different properties (plasmonic, gyroscopic, chiral or polarized molecules) in a rectangular cavity in the lower THz regime. Exploring isotropic as well asl magnetically biased gyrotropic particles. In general, the presented approach has implications for the design and optimization of cavity-based sensors, mode engineering, and other photonic devices.

1. L. B. Felsen and N. Marcuvitz, “Radiation and scattering of waves,” New Jersey, Wiley and Sons, 2001 ,2nd ed.