Quantum Mechanical-like Approach with Effective Hamiltonians Based on Resonant States in Optical Cavities

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Optical microcavities are extensively studied in solid-state physics due to the interaction between confined photons and excitons in the active layer leading to a strong coupling regime and even a Bose-Einstein condensate. Alternatively, a cavity with birefringent and active material enables the creation of synthetic fields for photons, where light polarization acts as the spin for electrons. The interaction between orthogonally polarized modes leads to various effects of solid-state physics, including the Rashba-Dresselhaus interaction [1], merons and antimerons (Bloch and Neel skyrmions) [2], persistent spin helix [3], and annihilation of exceptional points [4]. Although the Berreman [5] and Schubert [6] transfer matrix methods are well established (though time-consuming), many researchers prefer to use a simpler 2×2 effective Hamiltonian based on ideal resonator (Fig. 1 (a)) to describe each of the aforementioned effects.

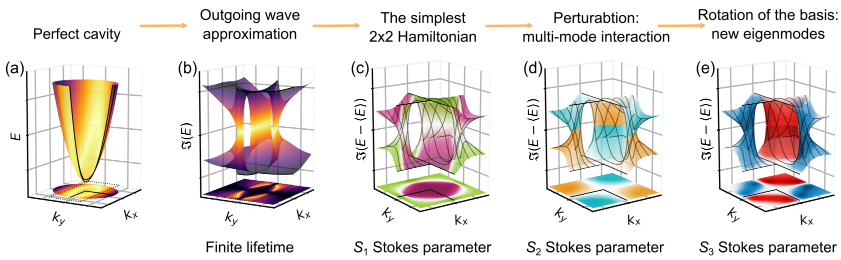

Figure 1: Schematic of the idea of presented theoretical approach. The imaginary part (i.e. finite lifetime) of polarized photons is presented.

Our work introduces a method based on resonant state and perturbation theory to derive formulas for the 2×2 effective Hamiltonians for various types of cavity coupling. Firstly, we replace the standard stack of distributed Bragg reflectors with δ-mirrors (Fig. 1 (b)), and, using Green's function, we obtain a simplified formula for the electric field. We adopted the perturbation theory for Green's function to obtain the multimode Hamiltonian, which can then be further simplified to the 2×2 effective Hamiltonian (Fig. 1 (c)) via the next perturbation method, which includes interactions with other states (Fig. 1 (d)). In the last phase, we proposed a formula for polarization patterns, which is essential for their accurate determination, and relies on the rotation of basis via perturbation theory (Fig. 1 (e)). The application of a solid-state approach to solve optical problems not only simplifies calculations, but also allows better understanding of various problems like topological systems or non-hemritian physics.

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