Changing Atom-Cavity Response with Single Atoms

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Optical cavities in the Fabry-Perot configuration (two parallel mirrors) work out as resonators for the electromagnetic field. Their natural transmission linewidth depends on the natural properties of the mirrors involved (transmission and reflection coefficients, and absorption rates) and the distance between them. However, one can modify and control this linewidth using the electromagnetically induced transparency (EIT) phenomenon. The EIT is a quantum interference phenomenon capable of altering the optical response of a medium, turning an initially opaque atomic sample into transparent for a given radiation field (probe field) upon the incidence of a second field (control field). Once an atomic system is trapped inside the optical cavity, its linewidth can be altered by adjusting the control field strength. This allows one to reach much narrower cavity linewidths when compared to the natural ones. This narrowing has an immediate application, which is the manufacture of frequency filters adjustable by external fields. However, in the single-atom regime, there is a fundamental limitation to this narrowing of the linewidth, since in this regime quantum fluctuations cannot be disregarded. With this in mind, in this work we focus on how the linewidth of an optical cavity behaves for different numbers of atoms trapped inside of it. In addition, we also investigate how the other system parameters, such as the atom-cavity coupling and the intensities of the probe and control fields, affect the linewidth. To this end, we numerically simulate the quantum system using Python and QuTip, interested in the stationary characteristic EIT transmission spectrum, from which we can measure the linewidth for each set of parameters. This is a rather challenging problem to approach since the Hilbert space dimension grows exponentially with the number of atoms inside the cavity, which imposes a computational limitation to the analysis. Ultimately, this work focuses on important unanswered questions and could show whether it is possible to observe a quantum signature in the transmission of these systems, shedding a light on both fundamental and practical gaps.