Nonlinear Scaling of Rabi Frequency with Driving Electric Field in Polar Quantum Systems

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Optical properties of atomic systems are determined by spatial symmetries, quantified in terms of multipolar transition moments. Their nonzero values are related to the selection rules describing which transitions may occur in a quantum system. Contrary, permanent multipolar moments are routinely neglected as causing trivial shifts in the energy spectrum of the system. This contribution studies the light-matter interaction regimes in which this commonly held belief is wrong.

A quantum system driven with a resonant plane wave undergoes a periodic transfer of population between its eigenstates. The effect is known as Rabi oscillations, whose frequency depends on the amplitude of the driving field and the transition dipole moment between the contributing states. However, this paradigmatic quantum optical effect is hardly ever analysed in polar systems, in which the broken inversion symmetry induces new phenomena. Polar systems support permanent dipole moments that vary in general for different eigenstates. Hence, the Rabi transitions of the population give rise to an additional oscillating dipole that is a source of radiation at the Rabi frequency [1]. This frequency can be controlled within the MHz to even THz range, potentially giving rise to all-optically tunable coherent radiation sources exploiting the polar nature of quantum systems [2, 3].

Nonvanishing values of the permanent dipole moments also affect the Rabi frequency itself. The Rabi frequency of non-polar systems scales linearly with the amplitude of the driving electric field. For highly polar systems subject to relatively strong fields, this scaling may be modified. In this talk, we will discuss analytical theory within and numerical results beyond the rotating wave approximation. They suggest the existence of high-field-intensity regimes in which the Rabi oscillations' frequency in polar systems may become robust and field-independent, as well as regimes where the frequency collapses back to near-zero values despite a strong driving field. The robust character may enable an improved coherent response of atomic ensembles subject to strong fields rapidly varying in space. Such conditions are met, e.g., in the vicinity of plasmonic metasurfaces, and we will present estimations of the improvement for selected example systems. The collapse to the linear regime, in which even stronger fields give rise to near-zero Rabi frequency values, on the other hand, may potentially be exploited for strong-field metrology. Control of the permanent dipole moments with an external field may provide a knob for tuning these effects for specific applications.

References

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