

Dipolar interaction in optically dense media: internal atomic structure matters

Aleksei Konovalov^{*1}

1. Institute for Theoretical Physics, University of Innsbruck, Technikerstraße 13a, 6020 Innsbruck, Austria

This work presents a theoretical investigation of the spectroscopy of dense, cold atomic clouds composed of multilevel atoms. We focus on regimes where the internal atomic structure plays a crucial role in determining collective optical properties such as the collective Lamb shift (CLS) and the cooperative decay rate (CDR) — phenomena originating from interatomic dipole–dipole interactions and manifested in the excitation spectra of dense ensembles.

In particular, we consider systems in which the manifold of excited atomic states consists of multiple energy levels with Zeeman substructure, a situation relevant for atoms with hyperfine structure. During the light-scattering process, such systems undergo through several types of dipolar interactions:

1. identical dipolar transitions (same transition frequencies and polarizations);
2. degenerate orthogonal dipoles (same transition frequencies, different polarizations);
3. non-degenerate parallel dipoles (different transition frequencies, same polarizations);
4. non-degenerate orthogonal dipoles (different transition frequencies and polarizations).

Consideration of the first type of processes is a canonical way to describe properties of optically dense media. The second type has been examined, for instance, in the theoretical framework developed by A. M. Rey and J. Ye [1], and their relevance has been demonstrated in experiments [2] showing their reveal for light scattering in classically-forbidden directions. Interaction between non-degenerate dipoles, third and fourth types processes, are usually not considered.

Using a generalized model of coherent dipoles that includes non-degenerate transitions, we demonstrate the impact of interaction between non-degenerate dipoles (marked here above as 3 and 4) on the CLS for dense clouds of alkali atoms. Moreover, we show that incorporation of these processes in theoretical framework can eliminate discrepancies between theory and experimental results reported in [3] and [4].

^{*}Aleksei.Konovalov@uibk.ac.at

References

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