Superfluorescence of Compact System: Exact Solution and Stochastic Treatment

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Superfluorescence, or cooperative spontaneous emission phenomenon, has been a topic of interest since 1954, when Dicke published his pioneering work on the coherence in spontaneous emission [1]. Despite the fact that throughout the evolution, the system develops macroscopic dipole moment, the initial stage of the process is especially sensitive to quantum effects. There are several approximate methods developed for two-level systems that replace quantum effects with either random initial conditions [2], or phenomenologically insert a stochastic source into the Maxwell-Bloch equations [3]. In both cases, the stochasticity successfully mimics quantum effects that trigger the collective coherent process and gives qualitatively correct results. However, there are several problems associated with these approaches, for instance, difficulties in the inclusion of incoherent processes or complexity of generalization to the realistic atomic-level structure.

Another problem that severely obstructs the full quantum treatment is extreme dimensionality scaling. Usually, the system size grows exponentially with the increasing number of particles. In certain conditions, the system has a permutation symmetry, which slows the growth to a polynomial law. However, even this reduction is not enough to describe realistic systems of a large number of particles. A possible way-around is the adoption of phase-space methods that replace the extremely high-dimensional density matrix with a quasi-probability density function [4], that satisfies the partial differential equation. To that end, second quantization and subsequent bosonization may greatly simplify not only the transition to the Fokker-Planck equation but also the exact numerical solution of the quantum master equation.

In this talk, we discuss the exact and stochastic modelling of the superfluorescence of a compact system of identical particles and compare the results of these two approaches. For the exact solution, we pursued the goal to develop the method of generalized second quantization that allows the inclusion of incoherent processes and takes advantage of permutation symmetry. Due to resulting bosonization, this method also gives an opportunity to transform the quantum master equation into a Fokker-Planck equation, which is afterwards sampled with the set of stochastic Ito equations. We discuss the issues that we encountered in the numerical implementation and demonstrate an excellent agreement between exact quantum expectation values and stochastic averages. We show that the number of particles enters in equations only as a parameter.

References

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