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Dynamics of a laser-cooled and trapped radiator interacting with the Holstein–Primakoff *SU*(1,1) coherent state

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Abstract

We study the interaction between a laser-cooled and trapped equidistant three-level atom (ion) and a single-mode cavity field. The dipole moment matrix transition elements between the adjacent atomic energy levels d_{12} and d_{23} are assumed to be different. This problem generalizes the model of a pair of indistinguishable two-level atoms. An intensity-dependent coupling is assumed between the three-level atom and the radiation field. In this situation, we suppose that at the initial moment the field is in the Holstein–Primakoff $SU(1,1)$ coherent state and obtain the exact analytical solution for the atom–field state vector. The quantum-statistical and squeezing properties of the radiation field are investigated. The obtained results are compared with those for the single two-level atom model. We observe that the exact periodicity of the squeezing revivals that was observed in the case of the single two-level atom is violated in the model involving the equidistant three-level radiator with different dipole moment matrix transition elements. In other words, the exact periodicity of the physical quantities can be destroyed only when more than two levels of the single-atom model are taken into account. Two limiting cases are considered. In the first case, when $d_{12} \to d_{23}$, the quantum-statistical and squeezing properties of the single-mode cavity field are similar to those for a pair of indistinguishable two-level atoms. In the second case, when $d_{12} \to 0$, the exact periodicity of the squeezing revivals takes place. This limiting case is equivalent to the single two-level atom model.

1. Introduction

The success of various techniques of laser cooling and trapping has stimulated great interest because it gives the possibility of investigating the properties of non-classical radiation in interaction with single localized atoms. For example, photon antibunching and sub-Poissonian photon statistics have been observed in experiments with trapped ions (Diedrich and Walther 1987, Schubert *et al* 1992). A squeezing experiment would require the localization of the atom in a region much smaller than the wavelength, since phase shifts due to atomic motion effectively destroy this phase-sensitive effect. For this reason, Vogel has proposed homodyne intensity-correlation measurements with a weak local oscillator (Vogel 1991). In this situation, the atomic motion could be suppressed by using trapped and laser-cooled ions.

Recently, trapped ions have been used to test the fundamental aspects of quantum mechanics in the process of generating non-classical states (Leibfried *et al* 2005, Reichle *et al* 2006).

At present, cold atoms and molecules are successfully used in many fields of physics and chemistry such as quantum information processes (Andre *et al* 2006), Bose–Einstein condensation of complex systems (Taglieber *et al* 2006) and new ultra-cold chemistry (Krems 2005). In the field of cold chemistry, the lower energy and the longer duration of collisions reveal new phenomena (Balakrishnan and Dalgarno 2001) and provide a deeper insight into chemical reactions. It should be emphasized that atomic physicists can now achieve the formation of molecules from ultra-cold atoms with the help of Feshbach resonances (Donley *et al* 2002, Regal *et al* 2003, Strecker *et al* 2003, Xu *et al* 2003, Jochim *et al* 2003, Cubizolles *et al* 2003, Durr *et al* 2004, Kleppner 2004).

