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Decoherence of cooled and trapped polariton under magnetic field

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ABSTRACT

An interaction between matter and light remains the most important physical mechanism which open path to explore the fundamental principles of quantum mechanics. In this paper, the dynamical behavior of the system of cooled and trapped polariton is studied. In particular, we analytically and numerically studied decoherence in a system of cooled polariton under the influence of a magnetic trap by evaluating physical parameters such as force and its corresponding torque, transition probability of founding the system in the excited state and energy. It's shown that an introduction of magnetic field in the system as a trap increases considerably the total energy of the system. In the same manner, we investigated the total entropy of the system and evaluated its entanglement. We showed that, the system reaches asymptotic values of entanglement of 0.37 after some fluctuations, meaning that the magnetic field reduces considerably decoherence in the system.

1. Introduction

In condensed matter or theoretical physic, the entire field of study of atomic and molecular particles is dominated by considering the motion of those particles. During this last decade, the fundamentals physics with trapped particles (ions, atoms or molecules) represents one of the most challenging and promising fields of investigation with impressive results [1]. The transport of electrons under high intensity laser pulse has been of particular interest and much progress has been achieved in laser matter interactions. They have a wide range of potential applications, such as x-ray lasers [2], fast ignition in laser fusion [3], laser plasma accelerator [4,5] and generation of fast ions [6,7]. But the laser on polariton dynamics is not fully understood.

A polariton is a quasi particle resulting from matter-radiation field interaction [8]. It has two different components: exciton and photon. The normal mode of coupled matter-radiation system, has been well known for at least 40 years [8] and the independent pioneering work of Tolpygo [9] and Huang [10] studied polariton. For a perfect description of our model, we assume that the entire system of polariton (exciton-radiation interaction) with surrounding environment behaves as a two-level system. This means that, it can lower or rise between two energy states namely ground and first excited state, all the remaining states being neglected. In fact, it's well mentioned in Ref. [11] that a system of photons and excitons interacting each other in confined medium behaves like a two-level system with two substates. This assumption is testified by Ref. [12] who also describe a polariton as an excitonic two-level system couple to a single photon mode. This research work focused on investigating phase diagram and spectrum of a modified Tavis-Cummings Model (TCM), describing vibrationally dressed two-level systems coupled to a cavity mode. Such an approximation is usually call the two-level approximation.

In our recent research work [13], we investigated the role of polariton in cooling and trapping processes, but did not investigate the effect of magnetic field in the process. It seems thus important to investigate the induced decoherence in the system when it is pertubated by a magnetic field, considered as a trap. We then provide detailed dynamic descriptions by following the motions of polariton under magnetic field which can become useful tools in studies of laser quasi particle interaction. With the invention by Ref. [14] of tunable dye laser light in 1966, important theoretical and experimental works on the action of photons on particles have been carried at the earlier of 1970 [15] where [16] made the first demonstration of light pressure on atoms, deflecting an atomic sodium beam with resonance radiation from a lamp. The first proposal to cool neutral atoms in counter-propagating laser beams was made by Ref. [17] in 1975. At the same time, a similar proposal was elaborated by Ref. [18] to the use of ions in ion trap and by Ref. [17] for neutral atoms in pairs of counter-propagating laser beams detuned slightly below a resonance transition of the atoms. Several research works then follow in the field of laser cooling

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of particles. One can list here [19], who published the first laser cooling experiment in which he cooled a cloud of Mg ion [20], who reported laser cooling of Ba^+ ions [21], who recognized the potential of intense narrow-band light for manipulating atoms and [22] who demonstrated the first modern experiments for the deflection of atomic beam with lasers (for more details in laser cooling of particles, see Refs. [23–25]). Those laser cooling experiments where terrible proofs of the mechanical effects (dissipative force) of light on matters.

In spites of the realizations of the further traps, the atoms are still able to move slowly in any direction and eventually, they diffuse out of the region. In order to both increase the confinement potential of the trap and reduce diffusion of trapped atoms, the force has to be position dependent. Consequently, currently traps in various variant, such as the dark-spot [26], the two-dimensional traps [27,28] and allowing simultaneous trapping of two different elements [29,30] or isotopes [31] attracted more research works [32,33]. Nowadays, many other types of traps are developed. One can list the optical wire trap for cool neutral atoms using a fictitious magnetic field induced by a nanofiber-guides light field [34], the magnetic trap on an atom chip [35,36], which the concept burn in 1995 after neutral atoms where trapped for the first time with a magnetic potential of a current carrying wire by Ref. [37] and after the first experimental realization of Bose-Einstein condensation (BEC) in 1995 [38,39]. Ref. [40] proposed to use planar nanofabricated surface currents for microscopic magnetic traps.

No mind the evolution of the science of trapping particles towards diverse types of traps, the field of laser cooling and trapping neutral atoms doesn't yet attend the prospected level, because several elements, such as environment, are not taking in to account, when performing cooling and trapping processes. Because of the wide use of the technology of laser cooling and trapping particles in a large research field, one should at time to time remember announces due to physical and chemical effect of the environment where the experiment is carried on. For this fact, we showed in our previous brief report [13] that physical parameters for a cooled and trapped polariton, that is force and its corresponding torque, transition probability amplitude of finding the cooled and trapped polariton in the excited state and energy release, are controlled by surrounding environment. Following similar analysis, we showed theoretically and numerically the role played by surrounding environment in laser cooling and trapping of polariton. In order to reduce those announced and increase cooled and trapped polariton parameters, we use a magnetic field which we considered as a trap. Our motivation for choosing this type of trap, as similar as does [41], come from the fact that, magnetic trap is the natural candidate for trapping both microscopic particles and large scale objects [42,43] in one hand and the electromagnetic field can be uses to confines particles with much less perturbation to their internal structure and minimal heating from the surrounding environment in other hand. Such trap exploits the interaction of the magnetic moment of the atom with the inhomogeneous magnetic field to provide spatial confinement [41].

This paper is divided into five parts organized as follow: in the second part we present the mathematical tools and techniques utilized in order to evaluate the needed parameters of our system which are force and its corresponding torque, transition probability for the system to be found in the excited state and required energy. In the third part, we present dynamic behavior of system of cooled and trapped polariton by use of magnetic field most numerically. Before concluding our work with some remarks and recommendations in section five, we look at the coherence of system by investigating it's entanglement in section four in order to enhance our arguments elaborated in the previous sections with theoretical analysis.

2. Model

2.1. Hamiltonian

Trapping can be looking as a simple conservation of particles in bottles which walls are immaterial rather than materials substances. A perfect qualitative description of the magnetic trap by Ref. [41] explains that the physical mechanism underlying the operation of magnetic trap is the adiabatic principle. The appropriate way to describe their operation is in terms of classical mechanics in which the particle is realized in the trap by pointing its magnetic moment antiparallel to the direction of the magnetic field. The Hamiltonian for interaction of a magnetic moment μ_B with a homogeneous field B is given by the relation that fellow, where we suggested the field to be directed by σ_3;

$$H_B = -\mu_B B \otimes \sigma_3. \tag{2.1}$$

But, it has been found that, inside the trap, the particle experiences lateral oscillations which are slow compared to their precision. Therefore the particle may be considered as experiencing a slowly rotating magnetic field. As a result, the magnetic moment μ_B points antiparallel to the local magnetic field lines and the Hamiltonian of the system can just take the normal form which follow,

$$H_B = \mu_B B \otimes \sigma_3. \tag{2.2}$$

These expressions for the Hamiltonian of the interacting system correspond to the spin fiability frequency gives by

$$h\omega_B = \frac{\mu_B}{I} B \otimes \sigma_3, \tag{2.3}$$

where I is the related spin equal to $^1/_2$ for particles. For more detail, refer to [44]. From the previous relations, the Hamiltonian H_B that characterizes the field-polariton interaction takes the following expression:

$$H_B = \frac{\omega_B}{2} \otimes \sigma_3. \tag{2.4}$$

In the relation above, $\omega_B = \lambda\mu_B B$ is the magnetic field frequency, λ is the gyromagnetic factor, μ_B the Bohr magneton and B the magnetic field define by,

$$B = \frac{1}{2}\{\cos(kz)\cos(\omega_B t) - \sin(kz)\sin(\omega_B t)\}. \tag{2.5}$$

To clearly understand the effect of magnetic field in laser cooling and trapping of polariton, we consider the following assumption: at first, we assumed that since laser cooling and trapping processes are always carried on in the real environment, therefore the Hamiltonian of the magnetic trap should be the real part; secondly, we assume that for a weak magnetic field with frequency ω_B, $\sin(\omega_B t) \to 0$ as $\omega_B \ll 1$. In this case, the second term to the right hand side of (2.5) vanishes. The graphical representation for the simplified expression of the magnetic field is represented as follow.

The Jaynes-Cummings model is presented in Ref. [45] as the perfect mathematical model that is use for the studies of classical aspects of spontaneous emissions and to testify the presence of Rabi oscillation in atomic excitation. In this model, the dynamic behavior of the dipole interaction is completely studied. In the semi-classical approach and considering our discussions in sec.1, the Hamiltonian of the two-level system, i.e. the polaritonic system with ground state $|0\rangle$ and first excited state $|1\rangle$, is usually expressed by $H = H_0 + H_{Ph}$. Here H_0 is the Hamiltonian of exciton well illustrated in Ref. [41] and H_{Ph} the photon's one. For the simple case of interaction of a polariton with a monochromatic laser light, the subjected atom raises energy levels and vice versa, well denoted by the Pauli matrix σ_1 (see Ref. [46]). Consequently, the Hamiltonian of the laser light is represented by (2.6) as follow:

$$H_{Laser} = -\mu E_0 \cos(\omega_l t) \otimes \sigma_1. \tag{2.6}$$

Adding in the system several expressions for Hamiltonian of both laser light and interaction laser light-matter, H_{Laser} and H_{Int} respectively, then we obtain the expression for the Hamiltonian of cooled and trapped polariton, which is,

$$H = H_0 + H_{Ph} + H_{Laser} + H_{Int}. \tag{2.7}$$

According to the fact that we aim to trap cooled polariton by use of