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Dynamics of two coupled qubits in a two-mode cavity through four-photon processes: Nonclassical properties under intrinsic decoherence

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ABSTRACT

The impact of the intrinsic decoherence on the dynamics of a system composed of two coupled qubits inside a two-mode cavity with a nondegenerate parametric amplifier is analytically investigated. High-order nonlinearity causes strong entanglement and mixedness, which are analyzed by using entropy, negativity, and log negativity. In the absence of intrinsic decoherence, it is found that qubit-qubit coupling improves the generation of population inversion, entanglement, and mixedness. The coupling acts as external decoherence in the presence of the intrinsic decoherence, and the quantum effects evolve monotonically to non-zero stationary values. The qubit-qubit entanglement is crucially dependent on the nonlinearity and the intrinsic decoherence. The stability of this entanglement is granted for small intrinsic decoherence.

1. Introduction

Quantum entanglement (QE) and purity are the main characteristics of quantum systems. They are now recognized as the most critical aspect of evolving new quantum technologies [1–3]. The entanglement can be created and preserved between completely separated qubits inside the cavity [4–10].

The high-order nonlinearity of the interactions between atoms and multi-mode cavity has been a subject of various applications in the quantum information [11–13]. The nonlinear models are widely used to study exotic or non-classical effects such as collapse and revival phenomena [14], quantum filters [15], bistability [16,17] and chaos [18]. Multiple photon processes play a very important role in the nonlinear interactions [19,20], which are useful resources for quantum information and metrology [21].

Quantum systems are completely affected by the surrounding environments due to their decoherence and dissipation effects. These effects inhibit the entanglement and the purity [22–24].

The two-qubit entanglement is investigated for different cases as: two-photon transition resulting from a squeezed field [25,26], and a non-linear k-photon interaction with a thermal field [27–29]. The amount of entanglement produced by nonlinear interactions in a two-qubit system is found to be substantially higher than that generated by linear coupling.

Our main goal here is to focus on the entanglement and the mixedness generated by the interaction between a two-qubit system inside a two-mode cavity containing a nondegenerate parametric amplifier. Therefore, we introduce a new physical model for this non-linear interaction and derive its dynamical density operator. This is followed by a discussion on the population inversion as well as on the entanglement and mixture quantified by the entropy, negativity and log negativity.

The paper is organized as follows: The proposed model of the intrinsic decoherence is presented in Sec. 2. While the dynamics of the quantum effects are discussed in Sec.3. Finally, in Section 4, the paper is concluded.

2. The physical model

The considered system is formed by identical two coupled qubits (A and B) with the same transition frequency ω between their lower and upper states $|0_i\rangle$ and $|1_i\rangle$ ($i = A, B$), which have the energies $\hbar\omega_0^i$ and

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