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Collapse–revival of quantum discord and entanglement

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HIGHLIGHTS

- The correlations dynamics of two atoms in the case of a micromaser-type system is investigated.
- A quasi-periodic collapse and revival phenomenon for quantum discord and entanglement is reported.
- A phenomenon of correlations revivals different from that of non-Markovian dynamics is revealed.
- The oscillations of time evolution of both quantum discord and entanglement are almost in phase in our system.
- Quantum discord and entanglement have similar evolution behavior in some time range.

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ABSTRACT

In this paper the correlations dynamics of two atoms in the case of a micromaser-type system is investigated. Our results predict certain quasi-periodic collapse and revival phenomena for quantum discord and entanglement when the field is in Fock state and the two atoms are initially in maximally mixed state, which is a special separable state. Our calculations also show that the oscillations of the time evolution of both quantum discord and entanglement are almost in phase and they both have similar evolution behavior in some time range. The fact reveals the consistency of quantum discord and entanglement in some dynamical aspects.

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1. Introduction

The existence of nonclassical correlations between distinct quantum systems is one of the fundamental differences between quantum and classical physics. Entanglement, which is a key resource in quantum information science, has been considered to be the only kind of nonclassical correlation. However, it has become clear by now that entanglement does not include all nonclassical correlations although most of the quantum computation and communication processes rely on it. The nonclassical correlation, which cannot be captured by entanglement measure, is called quantum discord [1]. Both entanglement and quantum discord have become a fundamental resource in quantum information processing and a number of theoretical studies have been performed on this subject in recent years [2]. Unfortunately, we do not have yet a closed theory for the description of the nonclassical correlations, and there is no clear evidence of the relation between quantum discord and entanglement [3], in spite of some calculations of quantum discord for several families of quantum states and comparison with the entanglement have been presented in the literature [4–6]. Recently some studies have also showed that quantum discord is a resource in the tasks of entanglement distribution [7,8], and an operational interpretation of quantum discord has been given that quantum discord is a quantitative measure about the performance in the quantum-state merging [9,10]. More recently, in Ref. [11], Streltsov and Zurek showed that if a measurement device is in a nonclassical state, the measurement results cannot be communicated perfectly by classical means. In this case some part of the information in the measurement apparatus is lost in the process of communication, and the amount of this lost information turns out to be the quantum discord. They also found that the information loss occurs even when the apparatus is not entangled with the system of interest. In addition, the study of nature of correlations in a quantum state has also attracted the impressive amount of attention and efforts for both of theoreticians and of experimentalists. There are many articles devoted to the investigations of this aspect [12–28]. A prevailing observation in all results obtained is that the discord is directly associated to non-trivial properties of states. Particularly, Knill and Laflamme showed that quantum computation in which only one qubit is in a nonmaximally mixed state, while the rest are in maximally mixed state, can achieve an exponential improvement in efficiency over classical computers for a limited set of tasks [29].

The studies of quantum correlations in different dynamical systems are another important topic not only from a fundamental point of view, but also for practical purposes [2,30,31]. For the nonce, many interesting phenomena of correlations dynamics have already been discovered, including entanglement sudden death [32] and sudden change of quantum discord [33], freezing of quantum correlations [27] and recovery of quantum correlations in absence of system-environment back-action [30,34,35]. In order to get more dynamical features of quantum correlations, in the paper we will consider a pair of two-level atoms going though a cavity one after another. A detailed understanding of the evolution of entanglement and quantum discord in the system is valuable for both fundamental theoretical investigations and experimentally realizable systems. We study the dynamics of a pair of such atoms numerically and predict certain quasi-periodic collapse and revival phenomena for quantum correlations when the field is in Fock state and the two atoms are initially in a special separable state, that is, the maximally mixed state.

2. Dynamics of the two atoms in a micromaser-type system

Let us consider a micromaser-type system in which atoms are injected at a rate low enough that at most one atom at a time is inside the cavity, and the time of flight through the cavity t is the same for every atom. For simplicity we will suppose that the cavity is of a non-leaky type. The cavity-QED experiments are, in fact, very close to such situation [36–39]. While an atom flies through the cavity, the coupled atom–field system is described by the Jaynes–Cummings Hamiltonian. The interaction Hamiltonian in a rotating frame at the cavity mode frequency and in the rotating wave approximation, at exact resonance, can be written as $H_I = g(\sigma_+ a + a^+ \sigma_-)$, where $a(a^+)$ denote the annihilation (creation) operators of the single-mode cavity field and $\sigma_+(\sigma_-)$ represent the raising (lowing) operators of the atom, and g is the atom–field coupling constant.