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Steady state quantum discord for circularly accelerated atoms

Jiawei Hu [a], Hongwei Yu [a,b,*]

[a] Center for Nonlinear Science and Department of Physics, Ningbo University, Ningbo, Zhejiang 315211, China

[b] Synergetic Innovation Center for Quantum Effects and Applications, Hunan Normal University, Changsha, Hunan 410081, China

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ABSTRACT

We study, in the framework of open quantum systems, the dynamics of quantum entanglement and quantum discord of two mutually independent circularly accelerated two-level atoms in interaction with a bath of fluctuating massless scalar fields in the Minkowski vacuum. We assume that the two atoms rotate synchronically with their separation perpendicular to the rotating plane. The time evolution of the quantum entanglement and quantum discord of the two-atom system is investigated. For a maximally entangled initial state, the entanglement measured by concurrence diminishes to zero within a finite time, while the quantum discord can either decrease monotonically to an asymptotic value or diminish to zero at first and then followed by a revival depending on whether the initial state is antisymmetric or symmetric. When both of the two atoms are initially excited, the generation of quantum entanglement shows a delayed feature, while quantum discord is created immediately. Remarkably, the quantum discord for such a circularly accelerated two-atom system takes a nonvanishing value in the steady state, and this is distinct from what happens in both the linear acceleration case and the case of static atoms immersed in a thermal bath.

* Corresponding author at: Center for Nonlinear Science and Department of Physics, Ningbo University, Ningbo, Zhejiang 315211, China.

E-mail addresses: hujiawei@nbu.edu.cn (J. Hu), hwyu@hunnu.edu.cn (H. Yu).

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1. Introduction

Quantum entanglement is at the heart of quantum information science and is a key resource in technologies based on quantum effects [1]. However, recent studies show that entanglement is not the only kind of quantum correlation that can be applied in quantum information science [2–5]. Ollivier and Zurek introduced the concept of quantum discord, which is defined as the difference between total correlations given by quantum mutual information and classical correlation, so as to characterize the nonclassical correlations [2]. Quantum discord is regarded as a more general measurement of quantum correlations than entanglement, since there exist separable quantum states with nonzero quantum discord.

Due to the inevitable interactions with external environments, a quantum system may lose its coherence. In particular, it has been found that, although local decoherence needs an infinite time, two entangled atoms may get separable within a finite time under the influence of an external environment [6,7]. Therefore, it is also of interest to see how quantum discord behaves under the influence of an environment. In this regard, Werlang et al. have investigated the dissipative dynamics of a two-qubit system, in which each qubit is coupled to its own channel in the Markovian regime. They have shown that in all cases where entanglement sudden death occurs, quantum discord vanishes only in the asymptotic limit [8]. Ferraro et al. have proved that, interactions with an arbitrary Markovian bath (both local and common) cannot lead to a sudden and permanent vanishing of quantum discord, unless the asymptotic steady state is reached [9]. In this sense, quantum discord is more robust than entanglement. Furthermore, the steady state quantum discord is not necessarily vanishing, e.g., when the qubits are strongly coupled to the environment [10], when the non-Markovian effects are considered [11], and when the system is in a cavity [12].

Recently, Bellomo and Antezza have proposed a new protocol to generate and protect quantum entanglement [13,14], assuming that the coupling is weak and the Born–Markov approximation applies. They consider two atoms which are immersed in a stationary environment out of thermal equilibrium, and find that entanglement between atoms with finite separations may survive even in the steady state. The effects of a non-equilibrium environment on a single three-level atom have been studied in Ref. [15], in which it has been shown that there exists non-vanishing steady quantum coherence for such a three-level atom.

Recently, there has been growing interest in the studies of quantum correlations in relativistic regimes [16–22]. It is well-known that, a uniformly accelerated observer perceives the Minkowski vacuum as a bath of thermal Rindler particles, which is known as the Unruh effect [23], so it is of interest to examine the behaviors of quantum discord under the influence of acceleration [16–19]. In this aspect, Datta has studied the quantum discord between two initially maximally entangled free scalar field modes, each of which is detected by an observer. It is shown that, when one of the observers is accelerated while the other is inertial, the amount of quantum discord is nonzero even in the limit of infinite acceleration [16]. Céleri et al. have considered the quantum discord of a pair of entangled two-level atoms, assuming that one of the atoms is accelerating while the other is inertial and isolated from the environment [17]. In contrast to the free field modes model [16], they find that the quantum discord is completely destroyed in high acceleration limit [17]. Compared with linear acceleration, a large acceleration, which is desired in the verification of the Unruh effect, is easier to be realized in the circular motion. However, a fundamental difference between circular and linear accelerations is that the radiation perceived by a circularly accelerated observer is non-thermal [24–27]. Therefore, a natural question is whether quantum correlations such as entanglement and quantum discord can be preserved in steady states for circularly accelerated atoms just as the case of atoms in a nonequilibrium environment [13,14]. In the present paper, we plan to study the dynamics of two mutually independent circularly accelerated two-level atoms which rotate synchronically with their separation perpendicular to the rotating plane, in the hope of answering this question.

2. The master equation

We consider a circularly accelerated two-atom system coupled with a bath of fluctuating massless scalar fields in the Minkowski vacuum. The total Hamiltonian is

$$H = H_A + H_F + H_I. \tag{1}$$