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Protecting quantum coherence of two-level atoms from vacuum fluctuations of electromagnetic field

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HIGHLIGHTS

- We study the dynamics of a two-level atom interacting with a bath of fluctuating vacuum electromagnetic field.
- For both a single and two-qubit systems, the quantum coherence cannot be protected from noise without a boundary.
- The insusceptible of the quantum coherence can be fulfilled only when the atom is close to the boundary and is transversely polarizable.
- Otherwise, the quantum coherence can only be protected in some degree in other polarizable direction.

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ABSTRACT

In the framework of open quantum systems, we study the dynamics of a static polarizable two-level atom interacting with a bath of fluctuating vacuum electromagnetic field and explore under which conditions the coherence of the open quantum system is unaffected by the environment. For both a single-qubit and two-qubit systems, we find that the quantum coherence cannot be protected from noise when the atom interacts with a non-boundary electromagnetic field. However, with the presence of a boundary, the dynamical conditions for the insusceptible of quantum coherence are fulfilled only when the atom is close to the boundary and is transversely polarizable. Otherwise, the

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quantum coherence can only be protected in some degree in other polarizable direction.

1. Introduction

Quantum coherence is an important concept in quantum theory. The superposition principle of quantum states summarize the characteristic features of quantum systems from their classical counterparts, which marks the coherence is a fundamental aspect of quantum physics [1]. As the technological progress in the last few decades, quantum coherence becomes a powerful resource in various aspects, such as low-temperature thermodynamics [2–6], quantum metrology [7,8] and solid-state physics [9,10]. Besides, the interference phenomena plays a key role in quantum optics experiments [11–14], as well as a series of quantum information processing tasks [15]. Conventionally, quantum coherence is regarded as a physical resource, which is associated with the capability of a quantum state to exhibit quantum interference phenomena. Recently, Baumgratz et al. proposed some rigorous measurements to quantify coherence, such as l_1 norm and relative entropy of coherence [16], which are distance-based measurements for such resources.

On the other hand, a realistic quantum system should be regarded as an open system due to the interaction between the system and its surrounding environment. For example, a two-level atom bathing in a vacuum fluctuations of electromagnetic field would suffers from decoherence, which means that quantum coherence would reduced due to the interaction between the atom and the environment. Moreover, the quantum decoherence can be affected by the Unruh effect in noninertial frames [17,18]. Considering that the coherence is not only a fundamental aspect of quantum physics but also a crucial resource in quantum information technology, it is essential to find strategies to protect it. Most recently, Bromley et al. found that under some suitable dynamic conditions, the quantum coherence is efficiently preserved from noise during the entire evolution [19].

In this paper we consider a static polarizable two-level atom which couples with a bath of fluctuating vacuum electromagnetic field. Our goal is to protect the quantum coherence by setting a reflecting boundary in the electromagnetic field, which would change the vacuum fluctuations. We first calculate the evolution of the l_1 norm and relative entropy of coherence for a single-qubit system. Two different cases, the electromagnetic field without or with the presence of a reflecting boundary, are considered. We are going to analyze under which conditions the coherence is totally unaffected by the vacuum fluctuations. We find that in an unbounded space, the quantum coherence cannot be protected during the whole evolution, which is due to the interaction between the two-level atom and the electromagnetic field. However, with the presence of a boundary, the quantum coherence can be frozen when the atom is close to the boundary and is transversely polarizable, which means that the quantum coherence can be protected perfectly. We then study the quantum coherence of a two-qubit state with maximally mixed marginals [20,21] and find that the results are similar to that of the single-qubit case.

The outline of the paper is as follows. In Section 2, we briefly introduce the methods to quantify coherence and discuss the dynamics of open quantum systems for a static polarizable two-level atom coupling with a bath of fluctuating vacuum electromagnetic field. In Section 3, we calculate the evolution of the l_1 norm and relative entropy of coherence for a single-qubit system. In Section 4, we study the evolution for a two-qubit system. We summarize and discuss our conclusions in the last section.

2. Coherence measures and dynamic evolution of a two-level atom system

In this section we recall the methods to measure coherence in the reference basis which is due to the off-diagonal elements of a density matrix ρ, for instance, the intuitive l_1 norm and the relative