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Effect of external field on the early stage decoherence

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Abstract. In this paper, the effects of an external field on the early stage decoherence are discussed both in the cavity QED and the spin chain channel. We calculate the evolution of the entanglement, find that the finite time disentanglement can be eliminated or induced by the present of an external field for some initial states.

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Key words: early stage decoherence, cavity QED, spin channel

1 Introduction

Entanglement and coherence are two basic conceptions in the quantum world, and are the foundation of the quantum information processing. In real systems, decoherence always take place because of the unavoidable interaction of these systems with their natural environment, leads to the decay of coherence and entanglement. Yu and Eberly [1] have studied the dynamics of bipartite entanglement between two atoms which coupling to their own dissipative environment respectively. They found that the entanglement can completely vanish in a finite time even with much slower local decoherence, termed entanglement sudden death (ESD). This surprising phenomenon which is contrary to our intuition on the decoherence is also appears in many other scenarios [2–6]. Yönaç *et al.* [2] study the disentanglement of two initially entangled Jaynes-Cummings atoms without any interaction between them; the effects of interaction between the particles and the couplings to the same environment have been discussed in Ref. [3, 4]; and the ESD is demonstrated can also happen in closed systems [7]. The experiment evidence is recently pressed [8, 9]. Although extensive works have been done in ESD, it is still unclear what causes it and what is the physics behind.

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These early stage decoherence may sometimes influence the quantum information process [10], e.g., in the entangled quantum information networks, the error correction technology [11,12] could make the very small degraded entanglement to be full usefulness, but incapacity in a totally disentanglement. An approach to quantum control is expected to avoid or unfold the entanglement sudden death as required. In this paper, we will demonstrate that the present of an appropriate external field will influence the decoherence process and to be a convenience approach to quantum control. Our paper is organized as follows, in Section 2, we introduce the measure of entanglement; the effects of external field in cavity QED and spin channel are discussed respectively in Section 3 and Section 4; concluding remarks are given in Section 5.

2 Measure of entanglement

To calculate the entanglement between two qubits, we choose the concurrence C defined by Wootters [13] as the convenient measure of entanglement. The concurrence varies from $C=0$ of a separable state to $C=1$ of a maximally entangled state. For a pure or mixed state of two qubits A and B, the concurrence may be calculated explicitly from the density matrix ρ as

$$C(\rho)=\max(0,\sqrt{\lambda_1}-\sqrt{\lambda_2}-\sqrt{\lambda_3}-\sqrt{\lambda_4}), \tag{1}$$

where the quantities λ_i are the eigenvalues in decreasing order of the matrix

$$\zeta=\rho(\sigma_y^A\otimes\sigma_y^B)\rho^*(\sigma_y^A\otimes\sigma_y^B), \tag{2}$$

where ρ^* denotes the complex conjugation of ρ in the standard basis and σ_y is the Pauli matrix expressed in the same basis as

$$\sigma_y=\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}. \tag{3}$$

3 Atoms in driven cavities

In the original paper of Yu *et al.* [1,2], two Jaynes–Cummings atoms A and B are located inside two spatially separated cavities a and b. The two atoms are initially entangled but have no direct interaction afterwards. The Hamiltonian is

$$H=H_A+H_B=\omega a^\dagger a+g(a^\dagger\sigma_-^A+a\sigma_+^A)+\omega b^\dagger b+g(b^\dagger\sigma_-^B+b\sigma_+^B). \tag{4}$$

Closer to experimental reality is the case of an external (classical) field [14] with drive amplitude ε added as an additional item $\varepsilon(a^\dagger+a)$. Use the analogous scenario in Ref. [2] but instead of two driven cavities, the Hamiltonian can be rewritten as

$$H=\omega a^\dagger a+g(a^\dagger\sigma_-^A+\sigma_+^A a)+\varepsilon_A(a^\dagger+a)+\omega b^\dagger b+g(b^\dagger\sigma_-^B+\sigma_+^B b)+\varepsilon_B(b^\dagger+b). \tag{5}$$