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Deterministic transfer for an unknown atomic entangled state via cavity QED

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Abstract. We present a physics scheme for transferring an unknown atomic entangled state via cavity QED. In the transfer process the interaction between atoms and a single-mode nonresonant cavity with the assistance of a strong classical driving field (substitute) replace the Bell-state measurements. The scheme is insensitive to both the cavity decay and the thermal field. In addition, the success probability can reach 1.0 in our scheme.

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Key words: transfer, unknown atomic entangled state, cavity QED

1 Introduction

Quantum entanglement is at the heart of quantum mechanics and plays a key role in quantum information processing, such as quantum teleportation [1], superdense-coding [2], quantum error correction [3] and secret key distribution [4]. Quantum teleportation is one of the most important applications of quantum entanglement in quantum communication. Quantum teleportation, first proposed by Bennett *et al*. [1] and experimentally realized by Bouwmeester *et al*. [5] and Boschi *et al*. [6], is a process to transfer unknown state to a remote location via a quantum channel aided by some classical communication. Cavity QED technique has been proved to be a promising candidate for experimentally realization of quantum communication schemes. Many teleportation schemes have been proposed based on cavity QED techniques [7–17]. Riebe *et al*. [18] and Barrett *et al*. [19] have implemented quantum teleportation of atomic qubits, respectively.

For teleportation, the joint Bell-state measurement on two particles is usually needed. Although the joint Bell-state measurement has been realized in Refs. [18, 19], it is quite

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difficult to operate. In addition, the cavity decay and thermal field are two vital obstacles to the realization of various cavity QED experiments. Recently, Wu *et al*. [20] proposed a quantum state transfer scheme for two atoms with a single resonant interaction without Bell-state measurement. But the scheme is sensitive to the cavity decay and thermal field. Wu *et al*. [21] proposed another scheme, also without Bell-state measurement, to transfer an unknown atomic entangled state, where the effect of cavity decay has been eliminated. However, it is still sensitive to the thermal field.

In this paper, we propose a scheme for transferring an unknown atomic entangled state via cavity QED. The distinct advantage of the scheme is that during the interaction between the two atoms and the cavity field, a classical field is simultaneously accompanied, thus the evolution of the quantum state is independent from the state of the cavity. So the scheme is insensitive to both the cavity decay and the cavity thermal field. Moreover, our scheme does not require the Bell-state measurement and the success probability can reach 1.0 in our scheme.

2 Interaction of two identical atoms and a sing-mode cavity

We consider two identical two-level atoms simultaneously interacting with a single-mode cavity field. At the same time, two atoms are driven by a strong classical field. In the large detuning $\delta \gg g$ and $2\Omega \gg \delta, g$ limit (where δ is the detuning between the atomic transition frequency ω_0 ($e \leftrightarrow g$) and the cavity frequency ω_a, g is the atom-cavity coupling constant and Ω is the Rabi frequency of the classical field), the effective interaction Hamiltonian in the rotating-wave approximation is [22]

$$H_{eff} = \lambda \left[\frac{1}{2} \sum_{j=1}^{2} \left(|e_j\rangle\langle e_j| + |g_j\rangle\langle g_j| \right) + \sum_{j,k=1, j\neq k}^{2} \left(s_j^+ s_k^+ + s_j^+ s_k^- + H.C. \right) \right], \tag{1}$$

where $\lambda = g^2/2\delta$, $s_j^+ = |e_j\rangle\langle g_j|$, $s_j^- = |g_j\rangle\langle e_j|$, and $|e_j\rangle$ and $|g_j\rangle$ are the excited and ground states of jth atom. The evolution operator of the system is given by [22]

$$U(t) = e^{-iH_0 t} e^{-iH_{eff} t}, \tag{2}$$

where

$$H_0 = \sum_{j=1}^{2} \Omega \left(s_j^+ + s_j^- \right). \tag{3}$$

From the above evolution operator, we can get the evolution with different initial states during the interaction time t between atoms and cavity.

3 Transfer of unknown atomic entangled state

Assume the entangled atomic state to be transferred is

$$|\Psi_{12}\rangle = \alpha |g_1\rangle|e_2\rangle + \beta |e_1\rangle|g_2\rangle. \tag{4}$$