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Teleportation of two-atom entangled state in resonant cavity quantum electrodynamics*

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An alternative scheme is presented for teleportation of a two-atom entangled state in cavity quantum electrodynamics (QED). It is based on the resonant atom–cavity field interaction. In the scheme, only one cavity is involved, and the number of the atoms needed to be detected is decreased compared with the previous scheme. Since the resonant atom–cavity field interaction greatly reduces the interaction time, the decoherence effect can be effectively suppressed during the teleportation process. The experimental feasibility of the scheme is discussed. The scheme can easily be generalized to the teleportation of N-atom Greeninger–Horne–Zeilinger (GHZ) entangled states. The number of atoms needed to be detected does not increase as the number of the atoms in the GHZ state increases.

Keywords: teleportation, two-atom entangled state, resonant cavity QED
PACC: 0365, 4250

Quantum teleportation, first suggested by Bennett *et al*,[1] is one of the cornerstones of quantum computation and quantum communication.[2−3] As described by Bennett *et al*,[1] teleportation usually involves three particles. Particle 1 to be teleported is initially prepared in an unknown state, particle 3 to receive the teleported state is prepared in a maximally entangled state with another particle 2, then a joint measurement is performed on the particles 1 and 2, and the outcome of this measurement is communicated through a classical channel to a receiver, who, with this information, applies an appropriate rotation to the particle 3 thus he can reconstruct the initial state of the particle 1. The important feature of the quantum teleportation described is the transmission of information without physical contact, in the context of initial entangled qubits(as a quantum channel) possessed by the sender and receiver. Experimental demonstrations of quantum teleportation through the process of parametric down conversion,[4,5] by nuclear magnetic resonance,[6] and in trapped ions,[7,8] have been reported.

Cavity quantum electrodynamics (QED), with Rydberg atoms crossing superconducting microwave cavity, provides one of available systems for generating entangled states and processing quantum information.[9] In the context of cavity QED, a number of schemes have been proposed for teleportation of an unknown atomic state.[10−12] Davidovich *et al*[10] have proposed a scheme to teleport an unknown atomic state between two high-Q cavities, which are initially prepared in an entanglement of zero- and one-photon states. Cirac and Parkins[11] have proposed two schemes for teleportation of an unknown atomic state in the microwave and optical regimes, respectively. The scheme also needs two cavities. Zheng[12] has proposed a scheme for teleportation of an unknown atomic state based on the resonant atom–cavity field interaction. The scheme requires only one cavity. The prominent feature of the scheme is that the decoherence effect can be effectively suppressed during the teleportation process, in respect that the resonant atom–cavity field interaction greatly reduces the interaction time. Other schemes have been proposed for teleportation of an unknown atomic state,[13−17] a cavity field state,[18−21] and a cavity field entangled state.[22−25]

In Ref.[26], the authors have proposed a scheme for teleportation of an unknown two-atom entangled state through the driven cavity QED. In the scheme, the quantum channel must first be prepared in a three-particle maximally entangled state (composed of two

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atoms to receive the teleported state and an additional atom), then one of the two atoms in the entangled state to be teleported and the additional atom are simultaneously sent through a cavity, in which the two atoms couple nonresonantly with the cavity mode and are driven by a strong classical field. Then the teleportation can be achieved by detecting the states of the two atoms in the entangled state to be teleported and the additional atom. The advantage of the scheme is that the effects of cavity decay and thermal field are all eliminated, based on the fact that the interaction Hamiltonian of the system is independent of the number of photons in the cavity field. The challenge of the scheme is that the two atoms must be simultaneously sent through a cavity, and they must be driven by a strong classical field during the process of their coupling with the cavity mode, otherwise there will be an error. And we can see that the scheme needs two cavities, one is used to prepare the quantum channel and the other is used to perform the state-measurement, which also increases the difficulty of the experimental implementation of the scheme.

In this paper, we propose an alternative scheme for teleportation of two-atom entangled state involving only one cavity, and we only have to detect two atoms. The scheme is based on the resonant atom–cavity field interaction. It is inspired by the proposal of step-by-step engineered multiparticle GHZ entangled states,[27,28] and the generalization of the scheme by Zheng.[12] The scheme can be easily generalized to the teleportation of arbitrary multi-atom GHZ-type entangled states, in which the number of the atoms required to be detected does not increase with increasing number of the atoms in the GHZ state.

Figure 1 displays the setup for teleportation of two-atom entangled state. Atoms $A_j (j = 1, 2, 3, 4, 5)$ employed here have a three-level Ξ configuration as sketched in Fig.2, in which the three states are $|e\rangle_j$, $|g\rangle_j$, and $|i\rangle_j$. Atoms 3 and 4 are initially prepared in an unknown entangled state. Atoms 1, 2, and 5 are produced in Zone B_i $(i = 1, 2, 5)$, respectively by the excitation of velocity-selected atomic beam effusing from oven O_i. Atoms 1 and 2 are the ones to receive the teleported state, and atom 5 is the additional atom. The classical microwave zones F_k (or F'_k, $k = 1, 2, 3, 4$), which are used to manipulate the atomic states, are turned to the transitions $|g\rangle_j \leftrightarrow |i\rangle_j$, $|g\rangle_j \leftrightarrow |i\rangle_j$, $|e\rangle_j \leftrightarrow |i\rangle_j$, and $|e\rangle_j \leftrightarrow |g\rangle_j$, respectively. C is an ideal millimetre-wave superconducting cavity. $D_{e(g)}$ and $\mathrm{D}_{i(g)}$ denote the state-selective field ionization detectors. Each real line with an arrow denotes the atomic path.

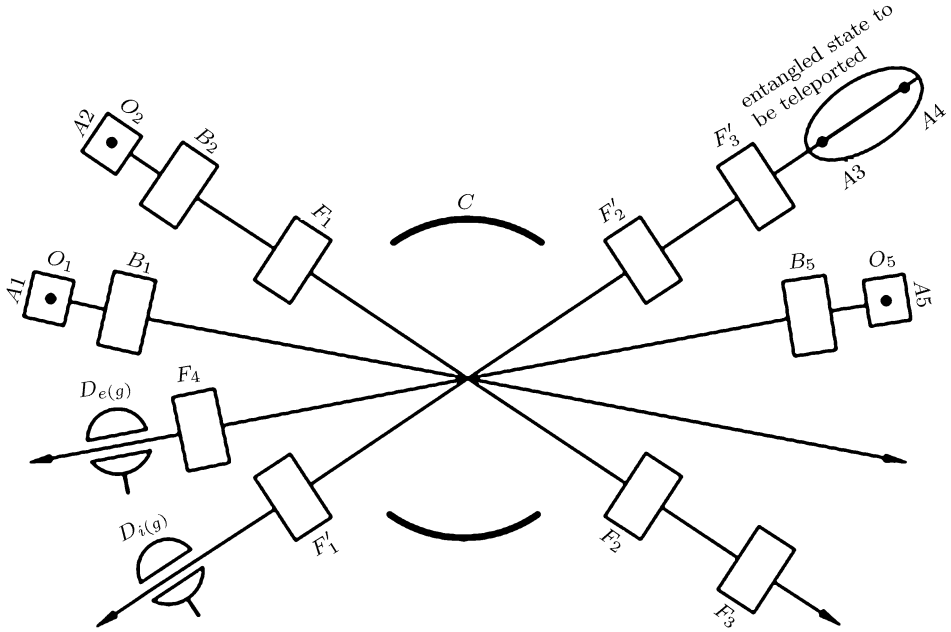


Fig.1. Setup for teleportation of two-atom entangled state.

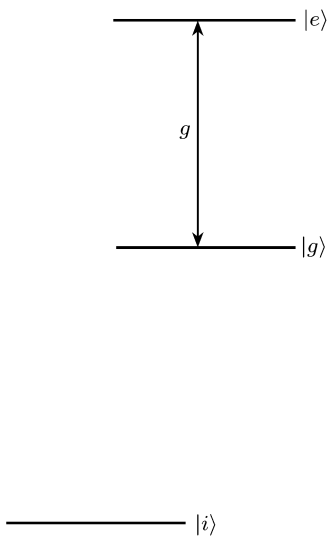


Fig.2. Three-level atom in the Ξ configuration.

We now consider the resonant interaction of the employed atoms with a cavity field. The relevant atomic levels $|e\rangle_j$, $|g\rangle_j$, and $|i\rangle_j$ are circular Rydberg states with principal quantum numbers 51, 50, and 49, respectively. The frequencies of the transitions $|e\rangle_j \leftrightarrow |g\rangle_j$ and $|g\rangle_j \leftrightarrow |i\rangle_j$ are respectively at 51.1 and 54.3 GHz. Thus, we can choose the frequency of the cavity mode in a way that only the transition $|e\rangle_j \leftrightarrow |g\rangle_j$ is affected by the cavity field. The frequency of the transition between the states $|g\rangle_j$ and $|i\rangle_j$ is highly detuned from the cavity frequency and thus the state $|i\rangle_j$ is not affected during the atom–cavity interaction. We assume that the transition $|e\rangle_j \leftrightarrow |g\rangle_j$ is coupled resonantly to the cavity mode with the vacuum Rabi oscillation frequency g. In the interaction picture, the effective interaction Hamiltonian for the atom–cavity system under the dipole and rotating wave approximation can be written as[9,28]

$$H = \mathrm{i}g\left(a^{+}\left|g\right\rangle_{jj}\left\langle e\right| - a\left|e\right\rangle_{jj}\left\langle g\right|\right), \tag{1}$$

where a^{+} and a are creation and annihilation operators for the cavity mode. Under domination of the Hamiltonian (1), the time evolution of the relevant states of the joint atom–cavity field system is given by

$$\begin{aligned}\left|g\right\rangle_j\left|n\right\rangle \rightarrow\ & \cos\left(g\sqrt{n}\tau\right)\left|g\right\rangle_j\left|n\right\rangle \\ & -\sin\left(g\sqrt{n}\tau\right)\left|e\right\rangle_j\left|n-1\right\rangle,\end{aligned} \tag{2}$$

$$\begin{aligned}\left|e\right\rangle_j\left|n-1\right\rangle \rightarrow\ & \cos\left(g\sqrt{n}\tau\right)\left|e\right\rangle_j\left|n-1\right\rangle \\ & +\sin\left(g\sqrt{n}\tau\right)\left|g\right\rangle_j\left|n\right\rangle,\end{aligned} \tag{3}$$

where $|n\rangle$ denotes the state with n photons in the cavity mode, τ is the effective interaction time.

Assume that two atoms 3 and 4 are initially prepared in the following entangled state

$$\begin{aligned}\left|\psi\right\rangle_{34} = \alpha\left|e\right\rangle_3\left|g\right\rangle_4 + \beta\left|g\right\rangle_3\left|e\right\rangle_4, \\ \left(\left|\alpha\right|^2 + \left|\beta\right|^2 = 1\right).\end{aligned} \tag{4}$$

And we want to teleport this state to that of another two atoms 1 and 2. In order to do so, firstly we send atom 1 in state $|e\rangle_1$ through a vacuum cavity, thus the state of the system evolves into

$$\begin{aligned}\left|\psi\left(\tau_1\right)\right\rangle_{\mathrm{A1-C}} = & \cos\left(g\tau_1\right)\left|e\right\rangle_1\left|0\right\rangle \\ & +\sin\left(g\tau_1\right)\left|g\right\rangle_1\left|1\right\rangle.\end{aligned} \tag{5}$$

If the interaction time between atom 1 and the cavity is chosen to satisfy $g\tau_1 = \dfrac{\pi}{4}$, the state of the system becomes

$$\left|\psi\right\rangle_{\mathrm{A1-C}} = \frac{1}{\sqrt{2}}\left(\left|e\right\rangle_1\left|0\right\rangle + \left|g\right\rangle_1\left|1\right\rangle\right). \tag{6}$$

Then atom 2 in state $|g\rangle_2$ is sent across microwave zone F_1, which leads to the transformation[28,29]

$$\left|g\right\rangle_2 \rightarrow \frac{1}{\sqrt{2}}\left(\left|i\right\rangle_2 - \left|g\right\rangle_2\right) = \left|-\right\rangle_2, \tag{7}$$

$$\left|i\right\rangle_2 \rightarrow \frac{1}{\sqrt{2}}\left(\left|i\right\rangle_2 + \left|g\right\rangle_2\right) = \left|+\right\rangle_2, \tag{8}$$

where two states $|-\rangle_2$ and $|+\rangle_2$ are defined as orthogonal states. After exiting from the microwave zone F_1, atom 2 is sent through the cavity, thus the state of the whole system evolves into

$$\begin{aligned}\left|\psi\left(\tau_2\right)\right\rangle_{\mathrm{A1-A2-C}} = & \frac{1}{\sqrt{2}}\Big\{\left|e\right\rangle_1\frac{1}{\sqrt{2}}\left(\left|i\right\rangle_2 - \left|g\right\rangle_2\right)\left|0\right\rangle + \left|g\right\rangle_1\frac{1}{\sqrt{2}}[\left|i\right\rangle_2 \\ & \times\left|1\right\rangle - \left(\cos\left(g\tau_2\right)\left|g\right\rangle_2\left|1\right\rangle - \sin\left(g\tau_2\right)\left|e\right\rangle_1\left|0\right\rangle\right)]\Big\}.\end{aligned} \tag{9}$$

If the interaction time is chosen in the way that $g\tau_2 = \pi$ is fulfilled, we have

$$\left|\psi^1\right\rangle_{\mathrm{A1-A2-C}} = \frac{1}{\sqrt{2}}\left(\left|e\right\rangle_1\left|-\right\rangle_2\left|0\right\rangle + \left|g\right\rangle_1\left|+\right\rangle_2\left|1\right\rangle\right). \tag{10}$$

Then atom 2 traverses the microwave zone F_2, which leads to the same transformation as F_1 leads to the transformation, thus

$$\left|\psi^2\right\rangle_{\mathrm{A1-A2-C}} = \frac{1}{\sqrt{2}}\left(\left|e\right\rangle_1\left|g\right\rangle_2\left|0\right\rangle + \left|g\right\rangle_1\left|i\right\rangle_2\left|1\right\rangle\right). \tag{11}$$

Afterward, atom 2 traverses the microwave zone F_3, leading to transformation $\left|i\right\rangle_2 \to \left|e\right\rangle_2$, thus we have

$$\left|\psi^3\right\rangle_{\mathrm{A1-A2-C}} = \frac{1}{\sqrt{2}}\left(\left|e\right\rangle_1\left|g\right\rangle_2\left|0\right\rangle + \left|g\right\rangle_1\left|e\right\rangle_2\left|1\right\rangle\right), \tag{12}$$

which constitutes the quantum channel for the teleportation.

Therefore, the state of the whole system reads

$$\begin{aligned}\left|\psi\right\rangle_{\mathrm{A1-A2-A3-A4-C}} = \left|\psi^3\right\rangle_{\mathrm{A1-A2-C}} \otimes \left|\psi\right\rangle_{34} = \frac{1}{\sqrt{2}}(&\left|e\right\rangle_1\left|g\right\rangle_2\left|0\right\rangle \\ &+ \left|g\right\rangle_1\left|e\right\rangle_2\left|1\right\rangle) \otimes (\alpha\left|e\right\rangle_3\left|g\right\rangle_4 + \beta\left|g\right\rangle_3\left|e\right\rangle_4),\end{aligned} \tag{13}$$

which can be rewritten as

$$\begin{aligned}\left|\psi\right\rangle_{\mathrm{A1-A2-A3-A4-C}} = \frac{1}{2}[&(\alpha\left|e\right\rangle_1\left|g\right\rangle_2 + \beta\left|g\right\rangle_1\left|e\right\rangle_2)\left|\Psi^+\right\rangle + (\alpha\left|e\right\rangle_1\left|g\right\rangle_2 - \beta\left|g\right\rangle_1\left|e\right\rangle_2)\left|\Psi^-\right\rangle \\ &+ (\alpha\left|g\right\rangle_1\left|e\right\rangle_2 + \beta\left|e\right\rangle_1\left|g\right\rangle_2)\left|\Phi^+\right\rangle + (\alpha\left|g\right\rangle_1\left|e\right\rangle_2 - \beta\left|e\right\rangle_1\left|g\right\rangle_2)\left|\Phi^-\right\rangle],\end{aligned} \tag{14}$$

where $\left|\Psi^{\pm}\right\rangle$ and $\left|\Phi^{\pm}\right\rangle$ are defined as

$$\begin{aligned}\left|\Psi^{\pm}\right\rangle &= \frac{1}{\sqrt{2}}\left(\left|e\right\rangle_3\left|g\right\rangle_4\left|0\right\rangle \pm \left|g\right\rangle_3\left|e\right\rangle_4\left|1\right\rangle\right), \\ \left|\Phi^{\pm}\right\rangle &= \frac{1}{\sqrt{2}}\left(\left|e\right\rangle_3\left|g\right\rangle_4\left|1\right\rangle \pm \left|g\right\rangle_3\left|e\right\rangle_4\left|0\right\rangle\right).\end{aligned} \tag{15}$$

Now we have to detect states $\left|\Psi^{\pm}\right\rangle$ and $\left|\Phi^{\pm}\right\rangle$. Firstly, atom 3 is sent through microwave zone F_3', leading to $\left|e\right\rangle_3 \to \left|i\right\rangle_3$, thus we have

$$\begin{aligned}\left|\Psi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|i\right\rangle_3\left|g\right\rangle_4\left|0\right\rangle \pm \left|g\right\rangle_3\left|e\right\rangle_4\left|1\right\rangle\right), \\ \left|\Phi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|i\right\rangle_3\left|g\right\rangle_4\left|1\right\rangle \pm \left|g\right\rangle_3\left|e\right\rangle_4\left|0\right\rangle\right);\end{aligned} \tag{16}$$

Next it crosses microwave zone F_2', leading to $\left|g\right\rangle_3 \to \frac{1}{\sqrt{2}}\left(\left|i\right\rangle_3 - \left|g\right\rangle_3\right) = \left|-\right\rangle_3$, and $\left|i\right\rangle_3 \to \frac{1}{\sqrt{2}}\left(\left|i\right\rangle_3 + \left|g\right\rangle_3\right) = \left|+\right\rangle_3$, respectively, thus formulae (16) become

$$\begin{aligned}\left|\Psi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|+\right\rangle_3\left|g\right\rangle_4\left|0\right\rangle \pm \left|-\right\rangle_3\left|e\right\rangle_4\left|1\right\rangle\right), \\ \left|\Phi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|+\right\rangle_3\left|g\right\rangle_4\left|1\right\rangle \pm \left|-\right\rangle_3\left|e\right\rangle_4\left|0\right\rangle\right);\end{aligned} \tag{17}$$

Then it enters into the cavity, and the evolution of the system is dominated by the effective Hamiltonian (1). If the interaction time is chosen to fulfil $g\tau_3 = \pi$, we have

$$\begin{aligned}\left|\Psi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|g\right\rangle_4\left|0\right\rangle \pm \left|e\right\rangle_4\left|1\right\rangle\right)\left|+\right\rangle_3, \\ \left|\Phi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|g\right\rangle_4\left|1\right\rangle \pm \left|e\right\rangle_4\left|0\right\rangle\right)\left|-\right\rangle_3;\end{aligned} \tag{18}$$

After exiting from the cavity, atom 3 traverses the microwave zone F_1', leading to the same transformation as F_2' leads to the transformation, thus one has

$$\begin{aligned}\left|\Psi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|g\right\rangle_4\left|0\right\rangle \pm \left|e\right\rangle_4\left|1\right\rangle\right)\left|i\right\rangle_3, \\ \left|\Phi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|g\right\rangle_4\left|1\right\rangle \pm \left|e\right\rangle_4\left|0\right\rangle\right)\left|g\right\rangle_3.\end{aligned} \tag{19}$$

Then the process for atom 3 is repeated for atom 4, i.e.

$$\begin{aligned}\text{atom4} \longrightarrow\ & F_3' \xrightarrow{\left|e\right\rangle_4 \to \left|i\right\rangle_4} F_2' \xrightarrow{\left|g\right\rangle_4 \to \left|-\right\rangle_4, \left|i\right\rangle_4 \to \left|+\right\rangle_4} \\ & C \xrightarrow{\tau_4 = \tau_3} F_1' \xrightarrow{\left|+\right\rangle_4 \to \left|i\right\rangle_4, \left|-\right\rangle_4 \to \left|g\right\rangle_4}.\end{aligned}$$

Then we have

$$\begin{aligned}\left|\Psi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|0\right\rangle \pm \left|1\right\rangle\right)\left|g\right\rangle_4\left|i\right\rangle_3, \\ \left|\Phi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|1\right\rangle \pm \left|0\right\rangle\right)\left|i\right\rangle_4\left|g\right\rangle_3.\end{aligned} \tag{20}$$

Now we send atom 5 which is initially in state $\left|g\right\rangle_5$, through the cavity, and the interaction time is chosen appropriately so that $g\tau_5 = \frac{\pi}{2}$ is fulfilled. Thus the state $\left|g\right\rangle_5\left|1\right\rangle$ just evolves into $-\left|e\right\rangle_5\left|0\right\rangle$, but the state $\left|g\right\rangle_5\left|0\right\rangle$ does not evolve, so we have

$$\begin{aligned}\left|\Psi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(\left|g\right\rangle_5 \mp \left|e\right\rangle_5\right)\left|g\right\rangle_4\left|i\right\rangle_3\left|0\right\rangle, \\ \left|\Phi^{\pm}\right\rangle &\to \frac{1}{\sqrt{2}}\left(-\left|e\right\rangle_5 \pm \left|g\right\rangle_5\right)\left|i\right\rangle_4\left|g\right\rangle_3\left|0\right\rangle.\end{aligned} \tag{21}$$

Then this atom traverses the microwave zone F_4, leading to the transformation

$$\left|g\right\rangle_5 \to \frac{1}{\sqrt{2}}\left(\left|g\right\rangle_5 - \left|e\right\rangle_5\right), \tag{22}$$

$$|e\rangle_5 \to \frac{1}{\sqrt{2}}\left(|g\rangle_5 + |e\rangle_5\right). \tag{23}$$

Therefore, we have

$$|\Psi^{\pm}\rangle \to \begin{cases} -|e\rangle_5 |g\rangle_4 |i\rangle_3 |0\rangle \\ |g\rangle_5 |g\rangle_4 |i\rangle_3 |0\rangle \end{cases}, \tag{24}$$

$$|\Phi^{\pm}\rangle \to \begin{cases} -|e\rangle_5 |i\rangle_4 |g\rangle_3 |0\rangle \\ -|g\rangle_5 |i\rangle_4 |g\rangle_3 |0\rangle \end{cases}.$$

As we can see, detecting only two of the three atoms $(3, 4, 5)$ is enough to distinguish between the states $|\Psi^{\pm}\rangle$ and $|\Phi^{\pm}\rangle$— atom 5 is required to be detected, but either atom 3 or atom 4 is also required to be detected. With this detection, we can apply an appropriate rotation to atoms 1 and 2 to achieve the teleportation.

The scheme can easily be generalized to the teleportation of n-atom entangled state of the GHZ-type

$$|\psi\rangle_{12\cdots n} = \alpha |ii\cdots i\rangle_{12\cdots n} + \beta |jj\cdots j\rangle_{12\cdots n}, \quad (i \neq j, i, j = e, g), \tag{25}$$

where α and β are unknown coefficients, and $|\alpha|^2 + |\beta|^2 = 1$, on the assumption that the quantum channel must be first prepared by engineering the entanglement of the cavity mode with n atoms to receive the teleported state. The number of the atoms required to be detected does not increase with increasing number of the atoms in the GHZ state. In other words, no matter how many atoms are involved in the GHZ state to be teleported, we only have to detect one of these atoms and an additional atom for teleporting this state.

We now give a brief discussion on the experimental realization of the proposed scheme based on the microwave cavity QED. Our scheme proposed here requires (1) resonant interaction between the Rydberg atom and cavity mode, (2) manipulating atomic states before and after the atom–cavity field interaction, (3) negligible cavity loss during the whole teleportation process, (4) no atomic spontaneous decay during the atom–cavity field interaction, (5) detection of atoms in required states, and (6) controlled time of interaction between the atom and cavity mode. We may employ the microwave cavity and Rydberg atoms used in the experiments performed by Haroche's group.[9] A photon in the cavity can have a lifetime of $T_r = 1\,\mathrm{ms}$, and the Rydberg atoms with the principal quantum numbers 49, 50, and 51 have a radiative time of $T_a = 3\times10^{-2}\,\mathrm{s}$. The manipulation of the atomic states can be done by applying preset microwave pulses to the corresponding zones. The detection of atoms in required states can be implemented by passing the atoms through the classical microwave field zones and field ionization counters. The time of interaction between each of the atoms and the cavity can be controlled by using a velocity selector and applying Stark field adjustment in order to make the atom resonant with the field for the right period of time. The coupling constant of the atoms to the cavity can be set to be $g = 2\pi \times 23.5\,\mathrm{kHz}$,[9,28] thus we have $\tau_1 = \frac{\pi}{4g} \simeq 5.4\,\mu\mathrm{s}$, $\tau_2 = \tau_3 = \tau_4 \simeq 21.3\,\mu\mathrm{s}$, and $\tau_5 \simeq 10.7\,\mu\mathrm{s}$ in our scheme. (At this time scale, the time needed for the classical microwave pulses can be neglected.). So the travelling time for the five atoms during the teleportation process can be assumed to be $\tau_1' = \frac{\pi}{4g} \simeq 54\,\mu\mathrm{s}$, $\tau_2' = \tau_3' = \tau_4' \simeq 213\,\mu\mathrm{s}$, and $\tau_5' \simeq 107\,\mu\mathrm{s}$, the total of these times being much shorter than T_r and T_a. Based on the fact that the two-atom entangled state and three-particle GHZ state (two atoms and one cavity mode) have already been experimentally realized by Haroche's group,[30,28] the preparation of the entangled state to be teleported and the quantum channel in the present scheme does not remain a great problem at all. Therefore, based on the current cavity QED technique, the present scheme might be achievable.

In summary, we have proposed an alternative scheme for teleportation of the two-atom entangled state. The scheme is based on the resonant atom–cavity field interaction. In this scheme, the quantum channel is prepared by means of step-by-step engineered multiparticle GHZ entangled states (composed of the atoms to receive the teleported state and the cavity mode). The state-measurement is completed by first analysing the atoms of the entangled state to be teleported from the GHZ entangled states (defined as $|\Psi^{\pm}\rangle$ and $|\Phi^{\pm}\rangle$), then replicating the cavity field state into an additional atom, and finally detecting the states of the additional atom and one of the atoms in the entangled state to be teleported. In contrast with the previous scheme, the advantage of the present scheme is that only one cavity is involved and only two atoms are required to be detected, which can decrease the difficulty of the practical implementation of the scheme. In the scheme, the time of interaction between the cavity and the atoms is greatly reduced since the atom–cavity field interaction is resonant, and consequently the decoherence effect can be dominated by the fast teleportation process.

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