Packaged entanglement states and particle teleportation. II. C-symmetry breaking

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Abstract

Packaged entanglement states encapsulate the necessary physical quantities as an entirety for completely identifying the particles. They are important for particle physics and matter teleportation. Here we proposed the new packaged entanglement states (of two particles and more than two particles) in which the charge does not conserve in the process of wave function collapse. We also discussed the particle teleportation and entanglement transfer using the new packaged entanglement states. It is shown that a particle always converts into its conjugating particle during the particle teleportation process.

Contents

1 Introduction

An early article [1] has studied the charge conjugation of a "particle-antiparticle" pair (A, B) and shown that the pair can form the so-called packaged entanglement states,

$$\begin{aligned} \left|\Psi^{+}\right\rangle_{AB} &= \frac{1}{\sqrt{2}}\left(|P\rangle_A \left|\bar{P}\right\rangle_B + \left|\bar{P}\right\rangle_A |P\rangle_B\right), \\ \left|\Psi^{-}\right\rangle_{AB} &= \frac{1}{\sqrt{2}}\left(|P\rangle_A \left|\bar{P}\right\rangle_B - \left|\bar{P}\right\rangle_A |P\rangle_B\right), \end{aligned} \tag{1.1}$$

where $|P\rangle$ denotes the particle's quantum state and $\left|\bar{P}\right\rangle$ denotes the antiparticle's quantum state. $|\Psi^{\pm}\rangle_{AB}$ are the eigenstates of the charge conjugation operator C [2]. These states package in all the necessary physical quantities for completely identifying the particles. They are different to the states with one degree freedom entanglement [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13], hyperentanglement [14, 15, 16, 17, 18] or multimode entanglement [19, 20, 21, 22, 23, 24]. Furthermore, the particles in the packaged entanglement states are indeterminate and hermaphroditic. Due to these interesting properties, the packaged entanglement states could be important for particle physics [2] and be useful in matter teleportation [25], medicine [26], remote control, and energy transfer.

However, the packaged entanglement states $|\Psi^{\pm}\rangle_{AB}$ are construct on basis of a particle-antiparticle pair in which the total charge is conserved (zero) in the wave function collapse. From a mathematical point of view, this is not the only possibility. There must exist other forms of packaged entanglement states in which the total charge are not conserved in the wave function collapse, i.e., the total charge are not equal before and after the wave function collapse. The physical properties and possible applications of these new packaged entanglement states are unknown yet.

In this article we constructed the mathematical expressions for the new packaged entanglement states and show that the wave function collapse does not result in a particle-antiparticle pair, but two identical particles (either two similar particles or two similar antiparticles). In other words, the total charge is not conserved in the wave function collapse and the C-symmetry is broken. The new packaged entanglement states can also be used as the quantum channels for particle teleportation. But the receiver's particle always conjugates to the sender's particle.

2 Packaged entanglement states

As mentioned before, the packaged entanglement states $|\Psi^{\pm}\rangle_{AB}$ are constructed under the constraint condition of zero total charge. Thus, they strictly obey the law of charge conservation. We shall now remove this constraint condition and construct the new packaged entanglement states which do not obey the law of charge conservation. Let us first study the packaged entanglement states of two particles and then generalize it to $M > 2$ particles later.

2.1 Packaged entanglement states of two particles

Consider the following two quantum states of a particle pair,

$$\begin{aligned} |\Phi^+\rangle_{AB} &= \frac{1}{\sqrt{2}}\left(|P\rangle_A |P\rangle_B + |\bar{P}\rangle_A |\bar{P}\rangle_B\right), \\ |\Phi^-\rangle_{AB} &= \frac{1}{\sqrt{2}}\left(|P\rangle_A |P\rangle_B - |\bar{P}\rangle_A |\bar{P}\rangle_B\right). \end{aligned} \tag{2.1}$$

Applying the charge conjugation operator C to $|\Phi^{\pm}\rangle_{AB}$, we have

$$\begin{aligned} C\,|\Phi^{\pm}\rangle_{AB} &= \frac{1}{\sqrt{2}}(-1)^J\left(|\bar{P}\rangle_A |\bar{P}\rangle_B \pm |P\rangle_A |P\rangle_B\right) \\ &= \pm(-1)^J\,|\Phi^{\pm}\rangle_{AB}. \end{aligned} \tag{2.2}$$

where $J = L + S$ is the total angular momentum quantum number, L is the orbital angular momentum quantum number, and S is the total spin quantum number.

Eq.(2.2) shows that $|\Phi^{\pm}\rangle_{AB}$ are also the eigenstates of the charge conjugation operator C. The C-parity (or charge parity) [27] depends on the total angular momentum quantum number J. As the eigenstates of C, therefore, $|\Phi^{\pm}\rangle_{AB}$ must exist.

Similarly to $|\Psi^{\pm}\rangle_{AB}$, the states $|\Phi^{\pm}\rangle_{AB}$ are also entanglement states because they cannot be expressed as the direct product of the particle state and antiparticle state.[28, 29] Furthermore, as the eigenstates of the charge conjugation operator C, the entanglement states $|\Phi^{\pm}\rangle_{AB}$ also package in all the physical properties capable of completely identifying the particles, i.e., the particle's electric charge (Q), baryon number (B), lepton number (L), isospin (I_3), charm (C), strangeness (S), topness (T), and bottomness (B').

The packaged entanglement states $|\Phi^{\pm}\rangle_{AB}$ have an interesting property. If a measurement is performed on the particle pair, $|\Phi^+\rangle_{AB}$ (or $|\Phi^-\rangle_{AB}$) will collapse and break the C-symmetry (the symmetry of physical laws under the charge conjugation operator C) [2, 30, 31]. More specifically, if a measurement is performed on A, it will collapse into either a particle, or an antiparticle. If A collapse into a particle, then B will also collapse into a particle, i.e., the wave function $|\Phi^+\rangle_{AB}$ (or $|\Phi^-\rangle_{AB}$) will collapse into $|P\rangle_A |P\rangle_B$. If A collapse into an antiparticle, then B will also collapse into an antiparticle, i.e., the wave function $|\Phi^+\rangle_{AB}$ (or $|\Phi^-\rangle_{AB}$) will collapse into $|\bar{P}\rangle_A |\bar{P}\rangle_B$. This process break the C-symmetry of the particle-antiparticle pair. Therefore, the law of charge conservation does not hold in this process.

2.2 Packaged entanglement states of more than two particles

The above stated packaged entanglement state can be generalized to a system with $M > 2$ particles. Because each particle has two states P and $\bar{P}$, there are totally 2^M packaged entanglement states, i.e.,

$$\begin{aligned}
|\Phi^{\pm}\rangle_1 &= \frac{1}{\sqrt{2}}\left(|P\rangle_1 |P\rangle_2 |P\rangle_3 \cdots |P\rangle_{M-1} |P\rangle_M \pm |\bar{P}\rangle_1 |\bar{P}\rangle_2 |\bar{P}\rangle_3 \cdots |\bar{P}\rangle_{M-1} |\bar{P}\rangle_M\right), \\
|\Phi^{\pm}\rangle_2 &= \frac{1}{\sqrt{2}}\left(|\bar{P}\rangle_1 |P\rangle_2 |P\rangle_3 \cdots |P\rangle_{M-1} |P\rangle_M \pm |P\rangle_1 |\bar{P}\rangle_2 |\bar{P}\rangle_3 \cdots |\bar{P}\rangle_{M-1} |\bar{P}\rangle_M\right), \\
|\Phi^{\pm}\rangle_3 &= \frac{1}{\sqrt{2}}\left(|P\rangle_1 |\bar{P}\rangle_2 |P\rangle_3 \cdots |P\rangle_{M-1} |P\rangle_M \pm |\bar{P}\rangle_1 |P\rangle_2 |\bar{P}\rangle_3 \cdots |\bar{P}\rangle_{M-1} |\bar{P}\rangle_M\right), \\
|\Phi^{\pm}\rangle_4 &= \frac{1}{\sqrt{2}}\left(|\bar{P}\rangle_1 |\bar{P}\rangle_2 |P\rangle_3 \cdots |P\rangle_{M-1} |P\rangle_M \pm |P\rangle_1 |P\rangle_2 |\bar{P}\rangle_3 \cdots |\bar{P}\rangle_{M-1} |\bar{P}\rangle_M\right), \\
|\Phi^{\pm}\rangle_5 &= \frac{1}{\sqrt{2}}\left(|P\rangle_1 |P\rangle_2 |\bar{P}\rangle_3 \cdots |P\rangle_{M-1} |P\rangle_M \pm |\bar{P}\rangle_1 |\bar{P}\rangle_2 |P\rangle_3 \cdots |\bar{P}\rangle_{M-1} |\bar{P}\rangle_M\right), \\
|\Phi^{\pm}\rangle_6 &= \frac{1}{\sqrt{2}}\left(|\bar{P}\rangle_1 |P\rangle_2 |\bar{P}\rangle_3 \cdots |P\rangle_{M-1} |P\rangle_M \pm |P\rangle_1 |\bar{P}\rangle_2 |P\rangle_3 \cdots |\bar{P}\rangle_{M-1} |\bar{P}\rangle_M\right), \\
&\cdots\cdots\cdots, \\
|\Phi^{\pm}\rangle_{2^{M-1}} &= \frac{1}{\sqrt{2}}\left(|\bar{P}\rangle_1 |\bar{P}\rangle_2 |\bar{P}\rangle_3 \cdots |\bar{P}\rangle_{M-1} |P\rangle_M \pm |P\rangle_1 |P\rangle_2 |P\rangle_3 \cdots |P\rangle_{M-1} |\bar{P}\rangle_M\right).
\end{aligned} \tag{2.3}$$

On the right sides of each equation in Eq.(2.3), the second half conjugates to the first half. Thus, if one apply the charge conjugation operator C to one of these equations, then he/she can obtain the same equation with a coefficient. This means that all the packaged entanglement states in Eq.(2.3) are the eigenstates of C.

If the numbers of Ps and $\bar{P}$s in the first half (or the second half) combinations on the right side of a state in Eq.(2.3) are equal (M must be an even number), then the C-symmetry holds in the collapse of this wave function. There are totally $C_M^{M/2} = M!/[(M/2)!]^2$ such states. If $M = 2$, then $|\Phi^{\pm}\rangle_3$ (see Eq.(2.3)) reduces to Eq.(1.1).

On the other hand, if the numbers of Ps and $\bar{P}$s in the first half (or the second half) combinations on the right side of a state in Eq.(2.3) are unequal, then the C-symmetry does not hold in the collapse of this wave function. For example, if a measurement is performed on $|\Phi^{\pm}\rangle_1$, then they will either collapse into the separable states $|P\rangle_1 |P\rangle_2 |P\rangle_3 \cdots |P\rangle_{M-1} |P\rangle_M$ or $\pm |\bar{P}\rangle_1 |\bar{P}\rangle_2 |\bar{P}\rangle_3 \cdots |\bar{P}\rangle_{M-1} |\bar{P}\rangle_M$. These processes break the C-symmetry. Therefore, the law of charge conservation does not hold in the collapse of these wave functions. If $M = 2$, then $|\Phi^{\pm}\rangle_1$ reduces to Eq.(2.1).

3 Applications

3.1 Particle teleportation to a single receiver

We shall now discuss the particle teleportation [25] using the packaged entanglement states in Eq.(2.1). The protocol is similar to that proposed in Ref. [1]. Let us first choose the packaged entanglement states $|\Phi^+\rangle_{AB}$ to carry out the calculation (see Fig. 1).

Consider that Alice want to teleport a particle X to Bob. Denote the quantum state of X as

$$|\phi\rangle_X = \alpha |P\rangle_X + \beta |\bar{P}\rangle_X , \tag{3.1}$$

where $\alpha = 1$, $\beta = 0$ if X is a particle, and $\alpha = 0$, $\beta = 1$ if X is an antiparticle.

Now create a quantum channel, i.e., a particle pair (A, B) in the packaged entanglement state $|\Phi^+\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|P\rangle_A |P\rangle_B + |\bar{P}\rangle_A |\bar{P}\rangle_B\right)$. One of the particles (particle A) is sent to Alice and another (particle B) is sent to Bob. Before Alice carry out any further operation, the complete state of the three particles (X, A, B) is

$$|\phi\rangle_X |\Phi^+\rangle_{AB} = \frac{\alpha}{\sqrt{2}}\left(|P\rangle_X |P\rangle_A |P\rangle_B + |P\rangle_X |\bar{P}\rangle_A |\bar{P}\rangle_B\right) + \frac{\beta}{\sqrt{2}}\left(|\bar{P}\rangle_X |P\rangle_A |P\rangle_B + |\bar{P}\rangle_X |\bar{P}\rangle_A |\bar{P}\rangle_B\right). \tag{3.2}$$

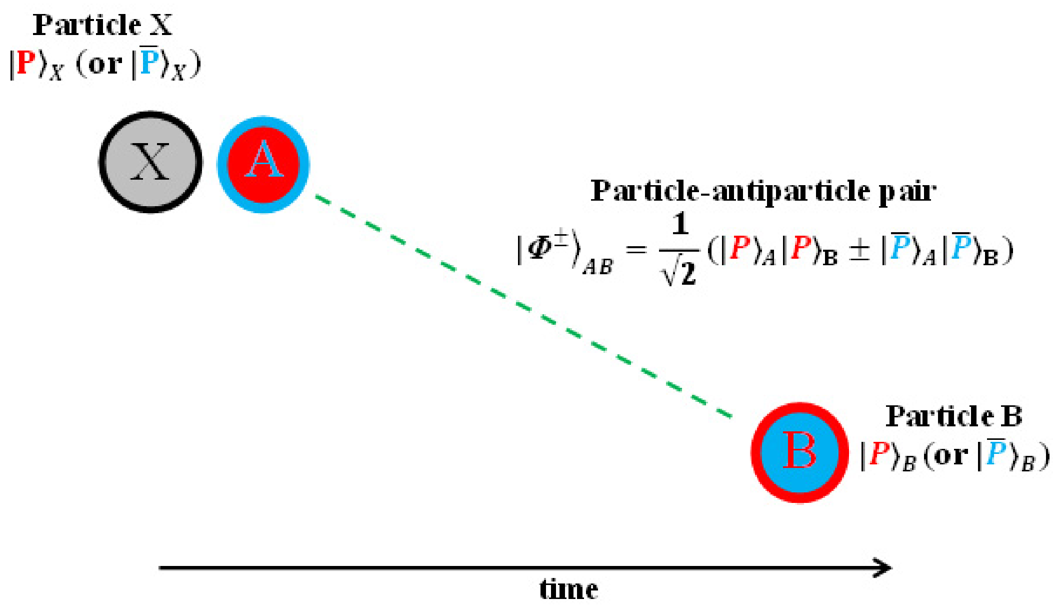

Figure 1: (Color online) Schematic diagram for particle teleportation using the packaged entanglement states $|\Phi^{\pm}\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|P\rangle_A |P\rangle_B \pm \left|\bar{P}\right\rangle_A \left|\bar{P}\right\rangle_B\right)$, and particle-antiparticle annihilation phenomenon.

Thereafter, Alice sends out her information stored on particle X by annihilating particle X with particle A. Eq.(3.2) will collapse into a state $|\Phi^+\rangle'_{XAB}$ which only has terms including $|P\rangle_X \left|\bar{P}\right\rangle_A$ and $\left|\bar{P}\right\rangle_X |P\rangle_A$, i.e.,

$$\begin{aligned} |\Phi^+\rangle'_{XAB} &= \alpha\left(|P\rangle_X \left|\bar{P}\right\rangle_A\right)\left|\bar{P}\right\rangle_B + \beta\left(\left|\bar{P}\right\rangle_X |P\rangle_A\right)|P\rangle_B \\ &= \alpha\left|P\bar{P}\right\rangle_{XA}\left|\bar{P}\right\rangle_B + \beta\left|\bar{P}P\right\rangle_{XA}|P\rangle_B . \end{aligned} \tag{3.3}$$

where $\left|P\bar{P}\right\rangle_{XA}$ and $\left|\bar{P}P\right\rangle_{XA}$ are the particles produced by the $|P\rangle_X \left|\bar{P}\right\rangle_A$ and $\left|\bar{P}\right\rangle_X |P\rangle_A$ annihilation, respectively.

Eq.(3.3) shows that Bob's particle B becomes related to X after Alice annihilate X with A. If $|\phi\rangle_X = |P\rangle_X$ (i.e., X is a particle, see Eq.(3.1)), then Eq.(3.3) becomes

$$|\Phi^-\rangle'_{XAB} = \left|P\bar{P}\right\rangle_{XA}\left|\bar{P}\right\rangle_B , \tag{3.4}$$

and B becomes an antiparticle conjugating to X. If $|\phi\rangle_X = \left|\bar{P}\right\rangle_X$ (i.e., X is an antiparticle), then Eq.(3.3) becomes

$$|\Phi^-\rangle'_{XAB} = \left|\bar{P}P\right\rangle_{XA}|P\rangle_B , \tag{3.5}$$

and B becomes an particle conjugating to X.

Eq.(3.4) and Eq.(3.5) show that Bob's particle B always conjugates to particle X after Alice sent out her information. This means that Bob can receive the packaged information of particle X sent to him by Alice (carried by X) and therefore can successfully decode the packaged information by referring to Eq.(3.4) and Eq.(3.5)

Similarly, one can repeat the above particle teleportation process using the packaged entanglement state $|\Phi^-\rangle_{AB}$ (see Eq.(2.1)). Now Eq.(3.3) becomes

$$|\Phi^-\rangle'_{XAB} = -\alpha\left|P\bar{P}\right\rangle_{XA}\left|\bar{P}\right\rangle_B + \beta\left|\bar{P}P\right\rangle_{XA}|P\rangle_B . \tag{3.6}$$

If $|\phi\rangle_X = |P\rangle_X$, then $|\Phi^-\rangle'_{XAB} = -\left|P\bar{P}\right\rangle_{XA}\left|\bar{P}\right\rangle_B$. If $|\phi\rangle_X = \left|\bar{P}\right\rangle_X$, then $|\Phi^-\rangle'_{XAB} = \left|\bar{P}P\right\rangle_{XA}|P\rangle_B$.

On can see that using $|\Phi^+\rangle_{AB}$, Bob always obtain a particle (particle B) conjugating to that of Alice (particle X). However, as shown in Ref. [1], when using $|\Psi^+\rangle_{AB}$, Bob always obtain a particle identical to that of Alice.

3.2 Particle teleportation to multiple receivers

We shall now show that Alice can teleport particles to multiple receivers [32, 33] using an entanglement state in Eq.(2.3). For simplicity, let us choose the first one in Eq.(2.3) (similar to the so-called GHZ state [34]) to carry out the calculation, i.e.,

$$\left|\Phi^{+}\right\rangle_1 = \frac{1}{\sqrt{2}}\left(|P\rangle^{\otimes M} + \left|\bar{P}\right\rangle^{\otimes M}\right). \tag{3.7}$$

One of the particles (particle A) is sent to the sender Alice and other $M-1$ particles are sent to the multiple receivers: Bob, Carl, David, Edward, Frank, $\cdots$. Before Alice carry out any further operation, Eq.(3.2) becomes

$$\begin{aligned}|\phi\rangle_X \left|\Phi^{+}\right\rangle_1 =& \frac{\alpha}{\sqrt{2}}\left[|P\rangle_X |P\rangle_A |P\rangle^{\otimes(M-1)} + |P\rangle_X \left|\bar{P}\right\rangle_A \left|\bar{P}\right\rangle^{\otimes(M-1)}\right] \\ &+ \frac{\beta}{\sqrt{2}}\left[\left|\bar{P}\right\rangle_X |P\rangle_A |P\rangle^{\otimes(M-1)} + \left|\bar{P}\right\rangle_X \left|\bar{P}\right\rangle_A \left|\bar{P}\right\rangle^{\otimes(M-1)}\right].\end{aligned} \tag{3.8}$$

Thereafter, Alice sends out her information stored on particle X by annihilating particle X with particle A. Eq.(3.8) becomes

$$\left|\Phi^{+}\right\rangle'_{XA(M-1)} = \alpha\left|P\bar{P}\right\rangle_{XA}\left|\bar{P}\right\rangle^{\otimes(M-1)} + \beta\left|\bar{P}P\right\rangle_{XA}|P\rangle^{\otimes(M-1)}. \tag{3.9}$$

If $|\phi\rangle_X = |P\rangle_X$, then $|\Phi^{-}\rangle'_{XA(M-1)} = \left|P\bar{P}\right\rangle_{XA}\left|\bar{P}\right\rangle^{\otimes(M-1)}$. If $|\phi\rangle_X = \left|\bar{P}\right\rangle_X$, then $|\Phi^{-}\rangle'_{XA(M-1)} = \left|\bar{P}P\right\rangle_{XA}|P\rangle^{\otimes(M-1)}$.

On can see that using $|\Phi^{+}\rangle_1$, the multiple receivers always receive the particles conjugating to particle X. This confirms that Alice can teleport particles to multiple receivers.

3.3 Transfer of packaged entanglement states

As mentioned before, Alice needs a quantum channel (a particle pair in an entanglement state) to perform a quantum teleportation. However, if two particles are spatially separated by large distance, then it is difficult to build up an entanglement state between them. It is even harder to put a separable particle-antiparticle pair into a packaged entanglement state. In this case, one should consider the possibility of transferring the entanglement state from other entangled particles to the objective particles which are originally unrelated. The purpose of this section is to study the entanglement transfer. The procedure is similar but not exactly like the entanglement swapping [35, 36]. The fundamental difference is that the entanglement swapping process use Bell measurements to swap the entanglements, but here we will use particle-antiparticle annihilation phenomenon to transfer the packaged entanglements (see Fig. 2).

Consider that particle A and B are originally in the packaged entanglement state $|\Phi^{+}\rangle_{AB}$, and particle C and D are in the packaged entanglement state $|\Phi^{+}\rangle_{CD}$, i.e.,

$$\begin{aligned}\left|\Phi^{+}\right\rangle_{AB} =& \frac{1}{\sqrt{2}}\left(|P\rangle_A |P\rangle_B + \left|\bar{P}\right\rangle_A \left|\bar{P}\right\rangle_B\right), \\ \left|\Phi^{+}\right\rangle_{CD} =& \frac{1}{\sqrt{2}}\left(|P\rangle_C |P\rangle_D + \left|\bar{P}\right\rangle_C \left|\bar{P}\right\rangle_D\right).\end{aligned} \tag{3.10}$$

Apparently, A and D are unrelated, B and C are unrelated. Now we wish to connect A and D in a packaged entanglement state without touching them. This can be achieved by annihilating B and C. Before Alice carry out any further operation, the complete state of the four particles (A, B, C, D) is

$$\begin{aligned}\left|\Phi^{+}\right\rangle_{ABCD} &= \left|\Phi^{+}\right\rangle_{AB}\left|\Phi^{+}\right\rangle_{CD} \\ &= \frac{1}{2}\left(|P\rangle_A |P\rangle_B |P\rangle_C |P\rangle_D + |P\rangle_A |P\rangle_B \left|\bar{P}\right\rangle_C \left|\bar{P}\right\rangle_D + \left|\bar{P}\right\rangle_A \left|\bar{P}\right\rangle_B |P\rangle_C |P\rangle_D + \left|\bar{P}\right\rangle_A \left|\bar{P}\right\rangle_B \left|\bar{P}\right\rangle_C \left|\bar{P}\right\rangle_D\right)\end{aligned} \tag{3.11}$$

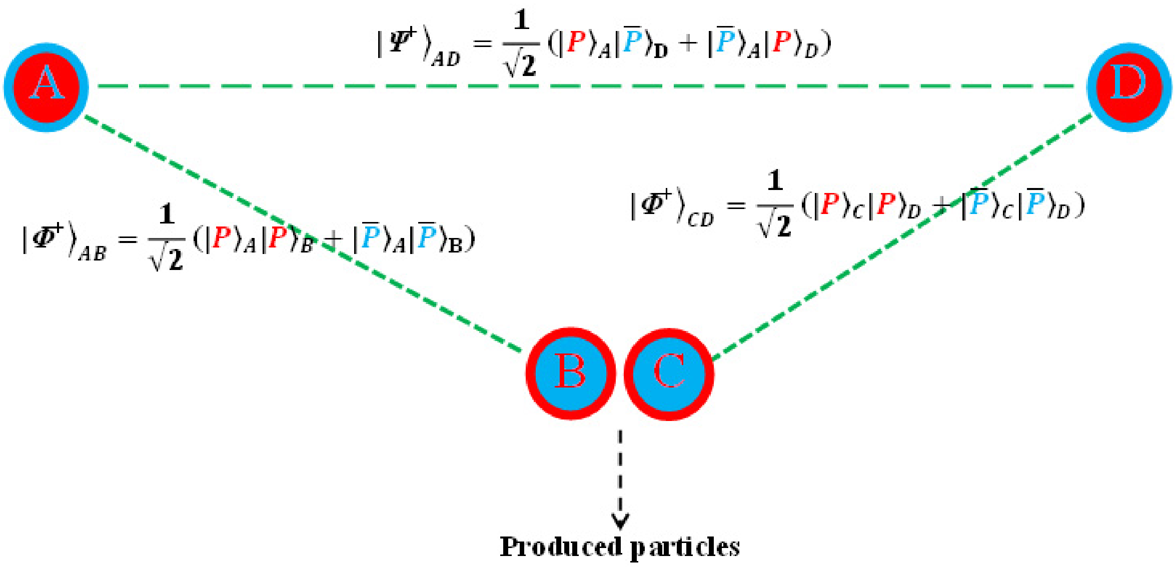

Figure 2: (Color online) Schematic diagram for the entanglement transfer from the packaged entanglement states $|\Phi^+\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|P\rangle_A|P\rangle_B + |\bar{P}\rangle_A|\bar{P}\rangle_B\right)$ and $|\Phi^+\rangle_{CD} = \frac{1}{\sqrt{2}}\left(|P\rangle_C|P\rangle_D + |\bar{P}\rangle_C|\bar{P}\rangle_D\right)$ to the packaged entanglement state $|\Psi^+\rangle_{AD} = \frac{1}{\sqrt{2}}\left(|P\rangle_A|\bar{P}\rangle_D + |\bar{P}\rangle_A|P\rangle_D\right)$.

Each particle in the packaged entanglement states is a mixture of a particle and an antiparticle, or a hermaphroditic particle. When particle B encounters C, the particle-antiparticle annihilation phenomenon [37] will force B and C to collapse into a pair of conjugated particles, or a particle-antiparticle pair in the separable states $|P\rangle_B|\bar{P}\rangle_C$ or $|\bar{P}\rangle_B|P\rangle_C$. Afterwards, the particle-antiparticle pair (B, C) will annihilate each other. Thus, the $|\Phi^+\rangle_{ABCD}$ in Eq.(3.11) will collapse into a state $|\Phi^+\rangle'_{ABCD}$ which only has terms including $|P\rangle_B|\bar{P}\rangle_C$ and $|\bar{P}\rangle_B|P\rangle_C$, i.e.,

$$\begin{aligned}|\Phi^+\rangle'_{ABCD} &= \frac{1}{\sqrt{2}}\left(|P\rangle_A|P\rangle_B|\bar{P}\rangle_C|\bar{P}\rangle_D + |\bar{P}\rangle_A|\bar{P}\rangle_B|P\rangle_C|P\rangle_D\right)\\ &= |\Psi^+\rangle_{AD}|P\bar{P}\rangle_{BC}.\end{aligned} \tag{3.12}$$

where $|\Psi^+\rangle_{AD} = \frac{1}{\sqrt{2}}\left(|P\rangle_A|\bar{P}\rangle_D + |\bar{P}\rangle_A|P\rangle_D\right)$ and $|P\bar{P}\rangle_{BC}$ are the particles produced by the $|P\rangle_B|\bar{P}\rangle_C$ and $|\bar{P}\rangle_B|P\rangle_C$ annihilation.

Eq.(3.12) shows that after the annihilation of particle B and C, particle A and D (originally unrelated) is now in the packaged entanglement state $|\Psi^+\rangle_{AD}$. If we choose $|\Phi^-\rangle_{AB}$ and $|\Phi^-\rangle_{CD}$ in Eq.(3.10), then Eq.(3.12) becomes $|\Phi^{--}\rangle'_{ABCD} = -|\Psi^+\rangle_{AD}|P\bar{P}\rangle_{BC}$, where $|\Psi^+\rangle_{AD} = \frac{1}{\sqrt{2}}\left(|P\rangle_A|\bar{P}\rangle_D + |\bar{P}\rangle_A|P\rangle_D\right)$. If we choose $|\Phi^+\rangle_{AB}$ and $|\Phi^-\rangle_{CD}$ in Eq.(3.10), then Eq.(3.12) becomes $|\Phi^{+-}\rangle'_{ABCD} = -|\Psi^-\rangle_{AD}|P\bar{P}\rangle_{BC}$, where $|\Psi^-\rangle_{AD} = \frac{1}{\sqrt{2}}\left(|P\rangle_A|\bar{P}\rangle_D - |\bar{P}\rangle_A|P\rangle_D\right)$.

Furthermore, the above transfer process can be performed in a sequence or chain with any number of packaged entanglement pairs, i.e.,

$$A - \overbrace{B\cdots C} - \overbrace{D\cdots E} - \overbrace{F\cdots G} - \overbrace{H\cdots I} - J\cdots.$$

Similarly, one can also use the packaged entanglement states $|\Psi^\pm\rangle_{AB}$ in Eq.(1.1) to do the calculation. For example, if we choose $|\Psi^+\rangle_{AB}$ and $|\Psi^+\rangle_{CD}$, then Eq.(3.12) becomes $|\Psi^+\rangle'_{ABCD} = |\Psi^+\rangle_{AD}|P\bar{P}\rangle_{BC}$, where $|\Psi^+\rangle_{AD} = \frac{1}{\sqrt{2}}\left(|P\rangle_A|\bar{P}\rangle_D + |\bar{P}\rangle_A|P\rangle_D\right)$.

The above discussion shows that in the entanglement transfer process, one can only obtain the states

$|\Psi^{\pm}\rangle_{AD}$, but cannot obtain the states $|\Phi^{\pm}\rangle_{AD}$. It does not matter which quantum channels you choose to do the entanglement transfer.

4 Conclusion

The properties of new packaged entanglement states with C-symmetry breaking are studied. This new packaged entanglement states are also the eigenstates of charge conjugation operator. The application of the new packaged entanglement states in particle teleportation and entanglement transfer are discussed. In the particle teleportation process with new packaged entanglement states, a particle is always teleported to the receiver as a particle conjugating to the original particle. In the entanglement transfer process, one can only obtain the states that obey the C-symmetry ($|\Psi^{\pm}\rangle_{AD}$), but cannot obtain the states that break the C-symmetry ($|\Phi^{\pm}\rangle_{AD}$).

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