Dynamics of entanglement under decoherence in noninertial frames*

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In this paper, we investigate the entanglement dynamics of a two-qubit entangled state coupled with its noisy environment, and plan to utilize weak measurement and quantum reversal measurement to study the entanglement dynamics under different decoherence channels in noninertial frames. Through the calculations and analyses, it is shown that the weak measurement can prevent entanglement from coupling to the amplitude damping channel, while the system is under the phase damping and flip channels. This protection protocol cannot prevent entanglement but will accelerate the death of entanglement. In addition, if the system is in the noninertial reference frame, then the effect of weak measurement will be weakened for the amplitude damping channel. Nevertheless, for other decoherence channels, the Unruh effect does not affect the quantum weak measurement, the only exception is that the maximum value of entanglement is reduced to $\sqrt{2}/2$ of the original value in the inertial frames.

Keywords: decoherence, noninertial frames, entanglement protection protocols

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1. Introduction

As is well known, quantum entanglement, as a special nonclassical correlation between the bipartite quantum systems, has occupied a significant position in quantum information processing, such as quantum dense coding, teleportation, etc.[1,2] Over the past years, quantum entanglement has been considered as a fundamental physical resource due to its essential role in revealing the nonlocality of quantum mechanics and its practical application in quantum information.[3]

Actually, a quantum system is inevitably subjected to the effect of its environment, such as in the case of some decoherence channels.[4–6] Recently, these interactions between the system and its environment have been widely investigated. These interactions cause the system to become entangled with its environment, they make dynamics of the system non-unitary, and they also lead to the degradation of coherence and entanglement.[2,7–14] Hence, the decoherence effect is not conducive to information processing in quantum theory. In order to prevent the entanglement from coupling to its noisy environment, we will make use of the weak measurement, which is based on the fact that the weak measurement can be perfectly reversed.[15–18] Recently, as is well shown, the weak measurement and quantum measurement reversal can effectively prevent entanglement from coupling to the amplitude damping decoherence for the entangled system.[19] However, using the weak measurement and quantum measurement reversal under other decoherence channels, such as phase damping and phase flip channels, to study the dynamics of quantum correlations has been seldom studied, which is one of our motivations in this work.

In particular, although numerous efforts have been devoted to studying the properties of entanglement, the detailed understanding of such a resource is limited to inertial systems.[20,21] Recently, the significance of comprehending entanglement has received considerable attention in a relativistic setting; for instance, when considering the implementation of quantum information processing tasks performed by observers in arbitrary relative motion.[22–25] The research of entanglement behaviors in a relativistic setting will not only provide a more complete framework for the quantum information theory, but also play an important role in understanding the entropy and information paradox of black holes.[26–28] Consequently, an increasing number of articles have discussed entanglement in a relativistic setting; in particular, how the Unruh effect influences the degree of entanglement.[29–39] The emphasis of this paper is placed on investigating the entanglement of a maximally entangled state coupled with decoherence channels, and the utilizing of weak measurement and quantum reversal measurement in noninertial frames.

The rest of this paper is organized as follows. In Section 2, we introduce the Unruh effect and the weak quantum measurement, together with the corresponding quantum measurement reversal. In Section 3, we show how the Unruh effect affects the entanglement protection protocols to prevent the entanglement, quantum entanglement of the system from coupling to various decoherence channels. Finally, we sum-

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marize our conclusion in Section 4.

2. Unruh effect and weak measurement with measurement reversal

At the outset, we introduce the Unruh effect for Dirac fields. As shown in Refs. [40]–[42], from an inertial viewpoint, we can describe the Dirac field by a superposition of the Unruh monochromatic modes, which is $|0\rangle_U = \otimes_\omega |0_\omega\rangle_U$ and $|1\rangle_U = \otimes_\omega |1_\omega\rangle_U$. Then, for a specific particle, the precise form of this role can be depicted as follows:

$$\begin{aligned} |0_\omega\rangle_U &= \cos r\,|0_\omega\rangle_{\rm I}\,|0_\omega\rangle_{\rm II} + \sin r\,|1_\omega\rangle_{\rm I}\,|1_\omega\rangle_{\rm II}\,, \\ |1_\omega\rangle_U &= |1_\omega\rangle_{\rm I}\,|0_\omega\rangle_{\rm II}\,, \end{aligned} \tag{1}$$

where $\cos r = (\mathrm{e}^{-2\pi\omega c/a}+1)^{-1/2}$, a is the acceleration of the observer, ω is the frequency of the Dirac particle, and c is the speed of light in vacuum. We assume that two observers, Alice and Bob, share an initial two-qubit entangled state, and consider that an accelerated observer (Bob) must stay in one region (I) due to these two (I and II) regions being causally disconnected.

In the following, a scheme for preventing the entanglement from coupling to decoherence is based on the fact that the weak quantum measurement can be reversed in Refs. [18] and [19]. The two-qubit weak measurement can be written as a non-unitary quantum operation

$$\begin{aligned} M_{\rm wk}(p_1) &= |0\rangle_1\langle 0| + \sqrt{1-p_1}\,|1\rangle_1\langle 1|\,, \\ M_{\rm wk}(p_2) &= |0\rangle_2\langle 0| + \sqrt{1-p_2}\,|1\rangle_2\langle 1|\,, \end{aligned} \tag{2}$$

where p_1 and p_2 are the weak measurement strengths. Then, the system is coupled with decoherence channel, under which condition quantum measurement reversal operations on the two particles are carried out separately. The two-qubit reversing measurement ($M_{\rm rev}$) can be written as a non-unitary operation:

$$\begin{aligned} M_{\rm wk}(p_{\rm r1}) &= \sqrt{1-p_{\rm r1}}\,|0\rangle_1\langle 0| + |1\rangle_1\langle 1|\,, \\ M_{\rm wk}(p_{\rm r2}) &= \sqrt{1-p_{\rm r2}}\,|0\rangle_2\langle 0| + |1\rangle_2\langle 1|\,, \end{aligned} \tag{3}$$

where $p_{\rm r1}$ and $p_{\rm r2}$ are the strengths of the reversing measurement. The optimal reversing measurement strength which gives the maximum amount of entanglement of the two-qubit state $\rho_{\rm r}$ is calculated to be $p_{rk} = p_k + D_k\bar{p}_k$, where $\bar{p}_k = 1-p_k$ $(k=1,2)$ with D_k being the magnitude of the decoherence, and the flowchart can be found in Ref. [19].

3. Entanglement dynamics under decoherence via Unruh effect

We now assume that Alice and Bob share an initial two-qubit entangled state:

$$|\phi\rangle = \alpha|00\rangle + \beta|11\rangle\,, \quad (|\alpha|^2 + |\beta|^2 = 1), \tag{4}$$

and we can obtain the density matrix as follows:

$$\rho_0 = \begin{pmatrix} |\alpha|^2 & 0 & 0 & \alpha\beta^* \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \alpha^*\beta & 0 & 0 & |\beta|^2 \end{pmatrix}. \tag{5}$$

Choose the concurrence as the entanglement measure, the concurrence of a two-qubit mixed state ρ in a noisy environment can be written as[43,44]

$$C(\rho) = \max\left\{0, \sqrt{\lambda_1} - \sqrt{\lambda_2} - \sqrt{\lambda_3} - \sqrt{\lambda_4}\right\}, \tag{6}$$

where λ_i are the eigenvalues, in decreasing order, of the matrix $\rho\tilde{\rho}$ with the spin-flipped matrix $\tilde{\rho} = (\sigma_y\otimes\sigma_y)\rho^*(\sigma_y\otimes\sigma_y)$. Due to the X structure of the density matrix, there is a simple closed expression for the concurrence present in all bipartitions:

$$C = 2\max\{0, \sqrt{\rho_{14}\rho_{41}} - \sqrt{\rho_{22}\rho_{33}}, \sqrt{\rho_{23}\rho_{32}} - \sqrt{\rho_{11}\rho_{44}}\}, \tag{7}$$

where ρ_{ij} are the elements of the density matrix ρ.

Owing to the unavoidable interaction between a quantum system and its environment, it is indispensable for us to have a whole comprehension of the dynamics of the entanglement states. In what follows, we will consider a system constituted by the two qubits A and B, which interact independently with their corresponding environments E_A and E_B, respectively.

3.1. Amplitude damping channel

Now, we consider the influence of amplitude damping channel on the two-qubit system, and the environment acts independently on their states. The amplitude-damping channel is a classical noise process describing the dissipative interaction between the system and the environment. In Refs. [45]–[47], we find that the action of decoherence channel on one qubit can be represented by the following phenomenological map:

$$\begin{aligned} |0\rangle_i\,|0\rangle_{E_i} &\to |0\rangle_i\,|0\rangle_{E_i}\,, \\ |1\rangle_i\,|0\rangle_{E_i} &\to \sqrt{\bar{D}_i}\,|1\rangle_i\,|0\rangle_{E_i} + \sqrt{D_i}\,|0\rangle_i\,|1\rangle_{E_i}\,, \end{aligned} \tag{8}$$

where $\bar{D} = 1-D$ $(0\le D\le 1)$. Equation (8) indicates that when there is one excitation in the system, it can either remain there with a probability $\bar{D}$, or be transferred into the environment with a probability D.

We now investigate how this decoherence map affects an initial entangled state, when the two particles are separately

coupled with the decoherence channels. Then, the resulting initial density operator of the system can be described as:

$$\rho_{ABE_AE_B}(0) = \rho_0(0) \otimes \rho_{E_AE_B}(0), \tag{9}$$

where ρ_{E_i} is the vacuum state of the environments. Then, we can calculate the entanglement of the total density matrix $\rho_{ABE_AE_B}(t)$ by using Eqs. (5), (8), and (9). Owing to amplitude damping decoherence, Alice and Bob now share the reduced-density matrix ρ_D obtained by taking the partial trace of $\rho_{ABE_AE_B}(t)$ over the environment

$$\rho_D = \mathrm{Tr}_{E_AE_B}[\rho_{ABE_AE_B}(t)],$$

which is given as

$$\rho_D = \begin{pmatrix} |\alpha|^2 + |\beta|^2 D_1 D_2 & 0 & 0 & \sqrt{\bar{D}_1\bar{D}_2}\alpha\beta^* \\ 0 & D_1\bar{D}_2|\beta|^2 & 0 & 0 \\ 0 & 0 & \bar{D}_1 D_2|\beta|^2 & 0 \\ \sqrt{\bar{D}_1\bar{D}_2}\alpha^*\beta & 0 & 0 & \bar{D}_1\bar{D}_2|\beta|^2 \end{pmatrix}. \tag{10}$$

The effect of decoherence on the initial state $|\phi\rangle$ can be investigated by evaluating the concurrence C_D of the quantum state ρ_D, according to Eq. (7), which is calculated to be

$$C_D = \max\left\{0, 2\sqrt{\bar{D}_1\bar{D}_2}|\beta|(|\alpha| - \sqrt{D_1D_2}|\beta|)\right\}. \tag{11}$$

After a detailed analysis, it is straightforward to see that when the decoherence magnitude is the strongest, that is, D_k=1 (k = 1,2) or $\sqrt{D_1D_2} \geq |\alpha/\beta|$, then $C_D = 0$, which indicates that this decoherence causes entanglement suddenly death (ESD), meaning that the two-qubit system becomes fully separable.

In order to prevent the entanglement from causing the decoherence, we will adopt a scheme by making use of weak measurement and the optimal reversing measurement.[19] Before the system couples to the noisy environment, they are separately subjected to weak measurement (M_{wk}). The qubit then undergoes the decoherence channel, and after that we bring the quantum measurement reversal into force. Then, the reduced-density matrix ρ_{r} shared by Alice and Bob, can be written as

$$\rho_{\mathrm{r}} = \frac{1}{A_{\mathrm{r}}}\begin{pmatrix} |\alpha|^2 + |\beta|^2 D_1 D_2 \bar{p}_1\bar{p}_2 & 0 & 0 & \alpha\beta^* \\ 0 & D_1\bar{p}_1|\beta|^2 & 0 & 0 \\ 0 & 0 & D_2\bar{p}_2|\beta|^2 & 0 \\ \alpha^*\beta & 0 & 0 & |\beta|^2 \end{pmatrix}. \tag{12}$$

where $A_{\mathrm{r}} = 1 + \{D_1\bar{p}_1(1 + D_2\bar{p}_2) + D_2\bar{p}_2\}|\beta|^2$, then we can obtain the concurrence C_{r} of the matrix ρ_{r} as follows:

$$C_{\mathrm{r}} = \max\left\{0, \frac{2|\beta|(|\alpha| - \sqrt{D_1D_2\bar{p}_1\bar{p}_2}|\beta|)}{1 + \{D_1\bar{p}_1(1 + D_2\bar{p}_2) + D_2\bar{p}_2\}|\beta|^2}\right\}. \tag{13}$$

As shown in Eq. (13), the calculations indicate that C_D is always not more than C_{r}, which means that we can prevent the entanglement from causing the decoherence by using the weak measurement and corresponding optimal reversing measurement.

Then, after two particles separately suffer the weak measurement and quantum measurement reversal, we will consider that the system is in a noninertial reference frame, which means that Alice stays stationary while Bob moves with uniform acceleration a. According to Eq. (1), we can rewrite the density matrix ρ_{r} in the Minkowski mode. Owing to the fact that Bob is causally disconnected from the region I and the information that is physically accessible to the observer is only encoded in the Minkowski mode, then we should trace over the modes region II and obtain the reduced density matrix as follows:

$$\rho_{AB} = \frac{1}{A_{AB}}\begin{pmatrix} \rho_{11} & 0 & 0 & \alpha\beta^*\cos r \\ 0 & \rho_{22} & 0 & 0 \\ 0 & 0 & \rho_{33} & 0 \\ \alpha^*\beta\cos r & 0 & 0 & \rho_{44} \end{pmatrix},$$

$$\begin{aligned} \rho_{11} &= (|\alpha|^2 + |\beta|^2 D_1 D_2 \bar{p}_1\bar{p}_2)\cos^2 r, \\ \rho_{22} &= |\beta|^2 D_1\bar{p}_1(1 + D_2\bar{p}_2\sin^2 r) + |\alpha|^2\sin^2 r, \\ \rho_{33} &= |\beta|^2 D_2\bar{p}_2\cos^2 r, \\ \rho_{44} &= |\beta|^2(1 + D_2\bar{p}_2\sin^2 r), \\ A_{AB} &= 1 + |\beta|^2\{D_1\bar{p}_1(1 + D_2\bar{p}_2) + D_2\bar{p}_2\}. \end{aligned} \tag{14}$$

The concurrence C_{AB} of the two-qubit state ρ_{AB} shared by Alice and Bob is then calculated to be

$$C_{AB} = \max\left\{0, \frac{2|\beta|\cos r(|\alpha| - \sqrt{D_1\bar{p}_1|\beta|^2 + (|\alpha|^2 + D_1D_2\bar{p}_1\bar{p}_2|\beta|^2)\sin^2 r}\sqrt{D_2\bar{p}_2})}{1 + \{D_1\bar{p}_1(1 + D_2\bar{p}_2) + D_2\bar{p}_2\}|\beta|^2}\right\}. \tag{15}$$

We now assume that if the system is in a noninertial reference frame at the beginning and takes the trace over the mode II, under which condition the qubits undergo the sequence of weak measurement, decoherence, and quantum measurement reversal, then we can obtain the reduced density matrix as follows:

$$\rho'_{AB}=\frac{1}{A'}\begin{pmatrix}\rho'_{11}&0&0&\alpha\beta^*\cos r\\0&\rho'_{22}&0&0\\0&0&\rho'_{33}&0\\\alpha^*\beta\cos r&0&0&\rho'_{44}\end{pmatrix},$$

$$\begin{aligned}\rho'_{11}&=|\alpha|^2\cos^2 r+|\beta|^2 D_1D_2\bar{p}_1\bar{p}_2+|\alpha|^2 D_2\bar{p}_2\sin^2 r,\\ \rho'_{22}&=D_1\bar{p}_1|\beta|^2+|\alpha|^2\sin^2 r,\\ \rho'_{33}&=D_2\bar{p}_2|\beta|^2,\quad \rho'_{44}=|\beta|^2,\\ A'&=1+\{D_1\bar{p}_1(1+D_2\bar{p}_2)+D_2\bar{p}_2\}|\beta|^2\\&\quad+|\alpha|^2 D_2\bar{p}_2\sin^2 r.\end{aligned}\tag{16}$$

Then, we can calculate the concurrence C'_{AB} of the system state ρ'_{AB} as follows:

$$C'_{AB}=\max\left\{0,\frac{2|\beta|\left(|\alpha|\cos r-\sqrt{D_2\bar{p}_2(D_1\bar{p}_1|\beta|^2+|\alpha|^2\sin^2 r)}\right)}{1+\{D_1\bar{p}_1(1+D_2\bar{p}_2)+D_2\bar{p}_2\}|\beta|^2+|\alpha|^2 D_2\bar{p}_2\sin^2 r}\right\}.\tag{17}$$

In order to facilitate the study of the influences of the amplitude damping decoherence magnitudes (D_1, D_2), measurement strengths (p_1, p_2), and Unruh effect (r) on concurrence, we will consider the maximally entangled state, the results are presented in Fig. 1.

As demonstrated in Fig. 1, we display the behaviors of concurrences C_D, $C_{\rm r}$, C_{AB}, and C'_{AB} for the maximally entangled state coupled with their noise environment. Entanglement degradation due to decoherence is shown in Fig. 1(a). Weak measurement with strength p_1 and p_2 and the optimal reversing measurement is plotted in Fig. 1(b). From the two figures, it follows that decoherence weakens the entanglement between the two particles and we can utilize the weak measurement and quantum reversal measurement to prevent the entanglement from coupling to decoherence channels. However, if the system is in a noninertial reference frame, as shown in Figs. 1(c) and 1(d), then the role of the entanglement preventing protocols is delayed, which means that the revival of concurrence will be later. Especially, we plot Figs. 1(b), 1(c), and 1(d) for D_1=0.6, D_2=0.8, and $r=\pi/4$.

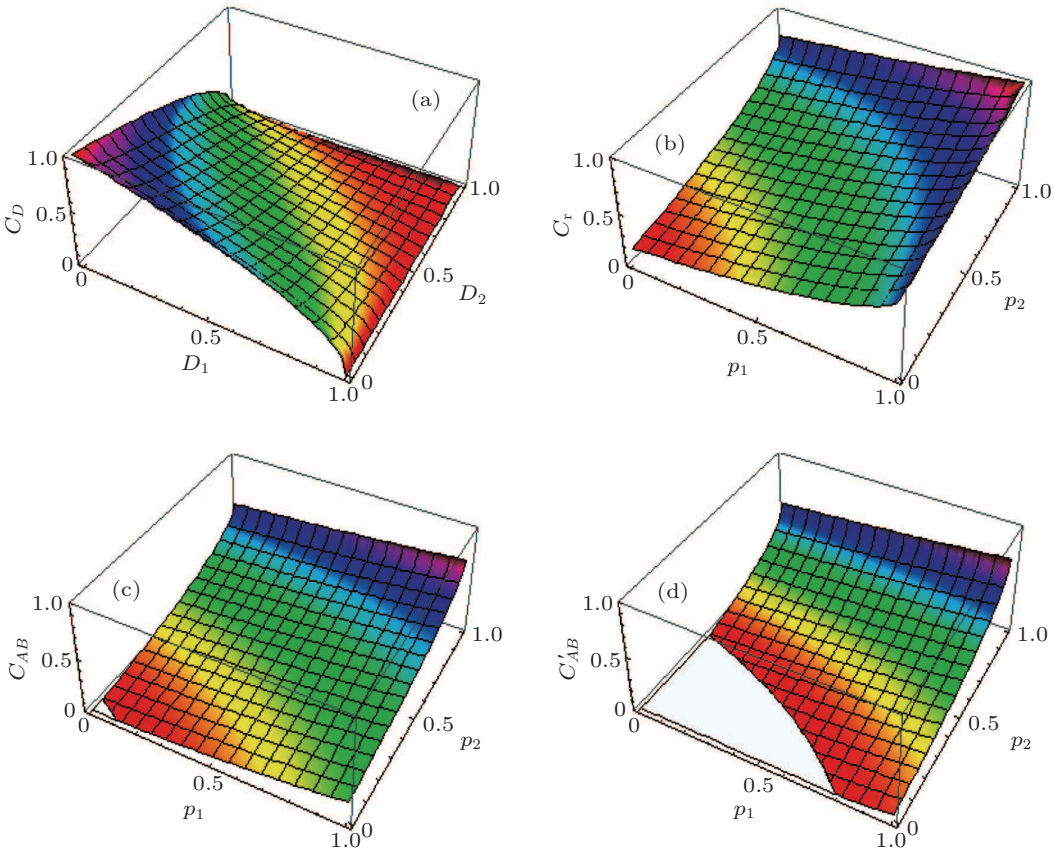


Fig. 1. (color online) Concurrence changes with decoherence, weak measurement, and Unruh effect.

3.2. Phase damping channel

The phase damping channel is a quantum noise that describes the loss of quantum coherence without losing energy. The coherence of the qubit state disappears without any change.[45] In this section we will discuss the dynamics of entanglement coupled with this channel. The corresponding unitary evolution mapped on a one-qubit system is given by

$$\begin{aligned} &|0\rangle_i|0\rangle_{E_i} \to |0\rangle_i|0\rangle_{E_i}, \\ &|1\rangle_i|0\rangle_{E_i} \to \sqrt{\bar{D}_i}|1\rangle_i|0\rangle_{E_i} + \sqrt{D_i}|1\rangle_i|1\rangle_{E_i}, \end{aligned} \tag{18}$$

where $\bar{D} = 1 - D$ $(0 \le D \le 1)$. As illustrated in Eq. (18), it can be understood that a state of two-level system does not change, but the state of the environment undergoes a transition without any energy exchange.

We now study how the entangled system dissipates in this decoherence. Although the initial state is a two-qubit entangled state $|\phi\rangle$, when it is coupled with the phase damping decoherence, the quantum state ρ_D shared by Alice and Bob can be given as

$$\rho_D = \begin{pmatrix} |\alpha|^2 & 0 & 0 & \sqrt{\bar{D}_1\bar{D}_2}\alpha\beta^* \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \sqrt{\bar{D}_1\bar{D}_2}\alpha^*\beta & 0 & 0 & |\beta|^2 \end{pmatrix}. \tag{19}$$

Then, the concurrence C_D of the quantum state ρ_D is calculated to be

$$C_D = \max\left\{0, 2|\alpha||\beta|\sqrt{\bar{D}_1\bar{D}_2}\right\}. \tag{20}$$

Our calculations indicate that the concurrence C_D always decreases monotonically, which does not cause the ESD.

Next, we will consider the effects of quantum entanglement protection protocols. After the system undergoes the sequence of weak measurement, decoherence, and reversing measurement, we can obtain the reduced density matrix shared by Alice and Bob, as follows:

$$\rho_{\rm r} = \frac{1}{A_{\rm r}} \begin{pmatrix} |\alpha|^2\bar{D}_1\bar{D}_2 & 0 & 0 & \alpha\beta^*\bar{D}_1\bar{D}_2 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \alpha^*\beta\bar{D}_1\bar{D}_2 & 0 & 0 & |\beta|^2 \end{pmatrix}, \tag{21}$$

where $A_{\rm r} = |\alpha|^2\bar{D}_1\bar{D}_2 + |\beta|^2$, and the concurrence $C_{\rm r}$ of the two-qubit state $\rho_{\rm r}$ shared by Alice and Bob is calculated to be

$$C_{\rm r} = \max\left\{0, \frac{2|\alpha||\beta|\bar{D}_1\bar{D}_2}{|\alpha|^2\bar{D}_1\bar{D}_2 + |\beta|^2}\right\}. \tag{22}$$

According to Eq. (13), the calculations indicate that C_D is always larger than $C_{\rm r}$, which means that entanglement protection protocols cannot prevent the decoherence from evolving.

We assume that the system is in a noninertial reference frame after the system has undergone measurement. Then, according to the Unruh effect, we obtain the reduced density matrix as follows:

$$\rho_{AB} = \frac{1}{A_{AB}} \begin{pmatrix} |\alpha|^2\bar{D}_1\bar{D}_2\cos^2 r & 0 & 0 & \alpha\beta^*\bar{D}_1\bar{D}_2\cos r \\ 0 & |\alpha|^2\bar{D}_1\bar{D}_2\sin^2 r & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \alpha^*\beta\bar{D}_1\bar{D}_2\cos r & 0 & 0 & |\beta|^2 \end{pmatrix}, \tag{23}$$

where $A_{AB} = |\alpha|^2\bar{D}_1\bar{D}_2 + |\beta|^2$, and the concurrence C_{AB} of the two-qubit state ρ_{AB} is then calculated to be

$$C_{AB} = \max\left\{0, \frac{2|\alpha||\beta|\bar{D}_1\bar{D}_2\cos r}{|\alpha|^2\bar{D}_1\bar{D}_2 + |\beta|^2}\right\}, \tag{24}$$

At the outset, we assumed that the system is in a noninertial reference frame and that it is taking the trace over the modes in region II. After the qubits sequentially undergo the weak measurement, decoherence, and quantum measurement reversal, we can acquire the reduced density matrix as follows:

$$\rho'_{AB} = \frac{1}{A'} \begin{pmatrix} |\alpha|^2\bar{D}_1\bar{D}_2\cos^2 r & 0 & 0 & \alpha\beta^*\bar{D}_1\bar{D}_2\cos r \\ 0 & |\alpha|^2\bar{D}_1\sin^2 r & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \alpha^*\beta\bar{D}_1\bar{D}_2\cos r & 0 & 0 & |\beta|^2 \end{pmatrix}, \tag{25}$$

where $A' = |\alpha|^2\cos^2 r\bar{D}_1\bar{D}_2 + |\alpha|^2\sin^2 r\bar{D}_1 + |\beta|^2$ and, thus, the concurrence C'_{AB} is then calculated to be

$$C'_{AB} = \max\left\{0, \frac{2|\alpha||\beta|\bar{D}_1\bar{D}_2}{|\alpha|^2\cos^2 r\bar{D}_1\bar{D}_2 + |\alpha|^2\sin^2 r\bar{D}_1 + |\beta|^2}\right\}. \tag{26}$$

In order to facilitate the study of the concurrence, the maximally entangled state, which is affected by the phase damping decoherence magnitudes (D_1, D_2), measurement strengths (p_1, p_2), and Unruh effect (r), should be considered, the results are presented in Fig. 2.

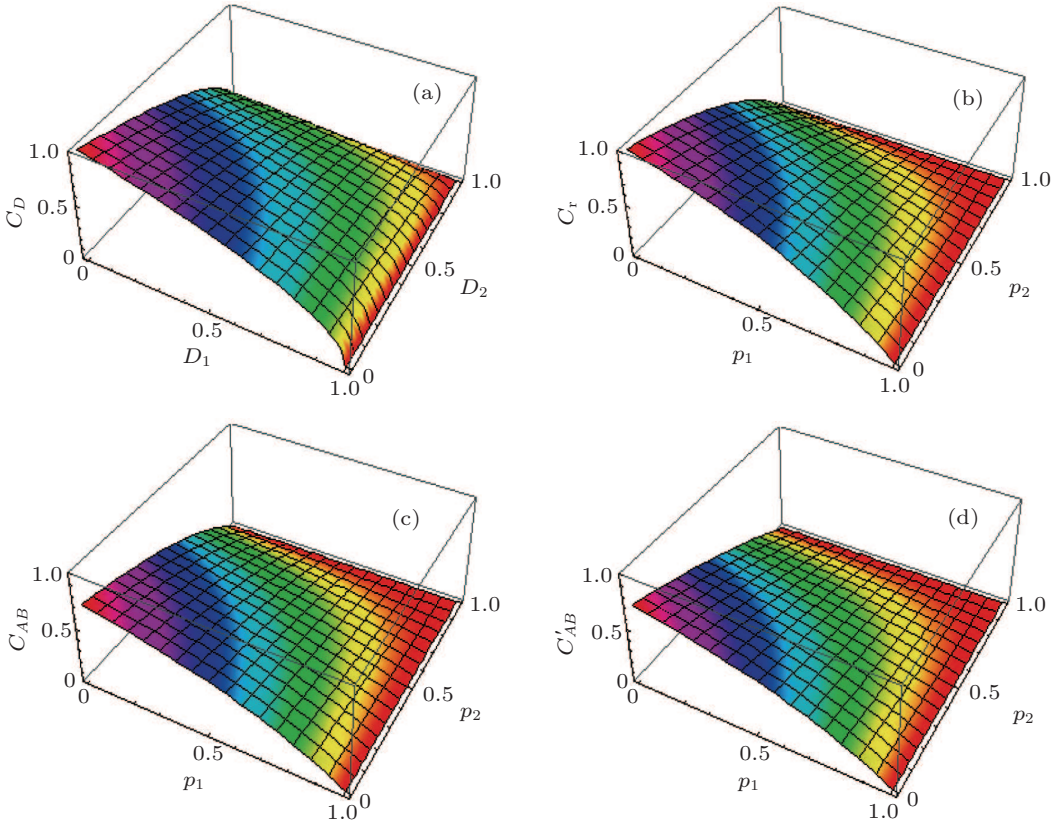


Fig. 2. (color online) Variations of concurrence with decoherence, weak measurement, and Unruh effect, respectively.

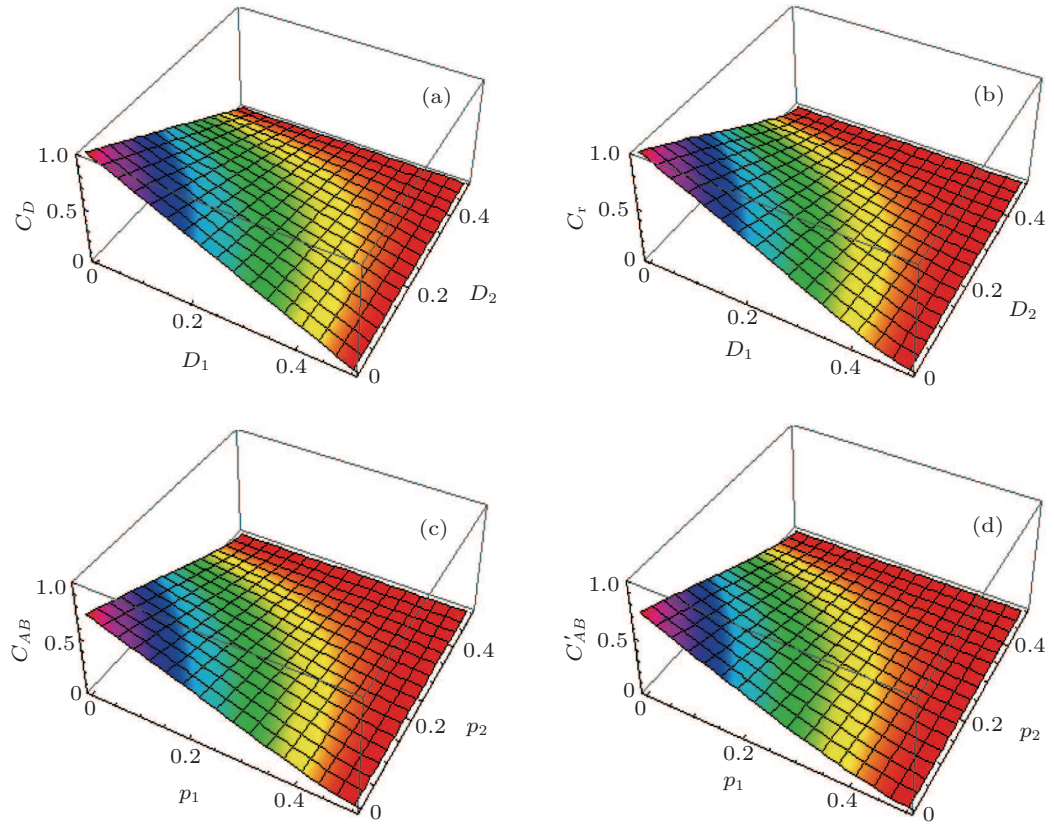


Fig. 3. (color online) Variations of concurrence with decoherence, weak measurement, and Unruh effect, respectively.

In Fig. 2, we have plotted the entanglement evolutions for the maximally entangled state coupled with their noise environments. It follows from Figs. 2(a) and 2(b) that the decoherence can weaken the entanglement between the two particles, and weak measurement and quantum measurement reversal cannot protect entanglement but can accelerate the death of entanglement. While, if the system is in a noninertial reference frame, the behaviors of C_{AB} and C'_{AB} are similar to that of $C_{\rm r}$, except that the maximum value is reduced to $\sqrt{2}/2$ of the original for the parameters D_1=0.6, D_2=0.8, and $r=\pi/4$.

Simultaneously, we also consider these flip channels such as phase flip, bit flip, and bit-phase flip, and obtain similar results to those of the phase damping channel. The results are shown in Fig. 3.

As demonstrated in Fig. 3, entanglement degradation due to decoherence is shown in Fig. 3(a). The weak measurement with strengths p_1 and p_2 and the optimal reversing measurement can circumvent decoherence, as shown in Fig. 3(b). Cases where the system undergoes the noninertial reference frame, weak measurement, decoherence, and reversing measurement are shown in Figs. 3(c) and 3(d). It is important to point out that the maximum value is reduced to $\sqrt{2}/2$ of the original especially for D_1=0.6, D_2=0.8, and $r=\pi/4$.

4. Conclusion

Quantum entanglement, as a prominent measure of quantum correlations, plays an important role in expanding its horizon beyond entanglement. In this paper, we investigate the entanglement dynamics of a two-qubit quantum state coupled with the decoherence environment, which will weaken the entanglement between the maximally entangled two-qubit states. At the same time, the weak measurement and quantum measurement reversal can indeed be useful for battling against amplitude damping decoherence, as demonstrated in Fig. 1. In other words, we can stabilize the quantum correlations by controlling the parameters in this decoherence environment. However, when the system is under other decoherence channels, such as phase damping and flip channels, the results show that the quantum entanglement protection protocols cannot prevent the entanglement from coupling to their noisy environments but can accelerate the death of entanglement, as shown in Figs. 2 and 3. In addition, we also reveal that, if the system is in a noninertial reference frame and one observer is in relative uniform acceleration a for the free Dirac field, then the role of the entanglement protection protocols is delayed by the Unruh effect, which means that the revival of concurrence is later when the observer's rate of acceleration is equal to $\pi/4$ under the amplitude damping decoherence. Nevertheless, for other decoherence channels, the Unruh effect does not affect the quantum weak measurement, the only exception is that the maximum value is reduced to $\sqrt{2}/2$ of the original.

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