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Bipartite entanglement induced by classically-constrained quantum dissipative dynamics

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HIGHLIGHTS

- A class of classically-constrained quantum bipartite dissipative dynamics is introduced.
- The entanglement generation is analyzed under those conditions.
- Dynamical constraints lead to a free decoherence space that allow the development of a stationary entangled state.
- Maximally entangled states are obtained from the interplay between the constraints and local external fields.

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ABSTRACT

The properties of some complex many body systems can be modeled by introducing in the dissipative dynamics of each single component a set of kinetic constraints that depend on the state of the neighbor systems. Here, we characterize this kind of dynamics for two quantum systems whose independent dissipative evolutions are defined by a Lindblad equation. The constraints are introduced through a set of projectors that restrict the action of each single dissipative Lindblad channel to the state of the other system. Conditions that guarantee a classical interpretation of the kinetic constraints are found. The generation and evolution of entanglement is studied for two optical qubits systems. Classically constrained dissipation leads to a stationary state whose degree of entanglement depends on the initial state. Nevertheless, independently of the initial conditions, a maximal entangled state is generated when both systems are subjected to the action of local Hamiltonian fields that do not commute with the constraints. The underlying physical mechanism is analyzed in detail.

1. Introduction

Superposition of different states corresponding to a bipartite quantum system may lead to entanglement, that is, quantum states whose statistical properties cannot be reproduced with local stochastic variables. Due to its central role in quantum information and quantum computation [1], in the last years an ever-increasing interest has been paid to its characterization [2].

Superposition of bipartite quantum states is degraded by interaction with uncontrollable degrees of freedom [3]. In contrast to quantum decoherence, the decay of entanglement, measured for example by concurrence [4], has non-usual properties such as its finite time decay [5] as well as the possibility of its sudden appearance at posterior times [6]. Non-standard decay properties were also found in the classical [7] and quantum [8] contributions of the total correlation (mutual information) between two systems [9,10].

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Even when the environment destroy the nonlocal properties of entanglement, it may also play a constructive role. The creation of entanglement by the action of a common bath was studied in many different physical situations [11–25]. Special interest have been paid to optical systems such as the Dicke model [21–23] where the dissipative decay dynamics is induced by interaction with the background electromagnetic field.

Added to the individual irreversible dynamics, dissipation of systems embedded in complex many body arranges may involves extra elements. For example, in quantum aggregates [26] the effects of a bath on a subsystem can be dependent on the state of another site [27]. This kind of constrained dissipation also arises in glassy systems. In fact, in contrast to static disordered interactions, glassiness can also be induced by dynamical constraints [28–32]. In a classical context, this situation is usually modeled by a Markovian master equation where the transition rates of each system depend on the state of the neighbors systems [32]. In Ref. [33] it was introduced a quantum version where the underlying evolution is given by a Lindblad equation and a set of projection operators introduce the constraints.

Constrained dissipation lead to an effective interaction between subsystems. As the dissipative dynamics admits a Markovian description [32,33], we expect that some entanglement may be generated by this mechanism [11]. Motivated by the previous physical situations, in this paper we study the production and evolution of entanglement for systems whose dissipative evolution is a constrained one. Our main theoretical goal is to characterize which kind of stationary entangled states may be generated by the constraints when they admit a classical interpretation [32]. The classicality property seems to be a very restrictive condition for the generation of entanglement. Nevertheless, focusing our analysis on a bipartite dynamics, we find that the joint action of classical dissipative constraints and local unitary evolutions may drive the dynamics to maximal entangled states.

We introduce a generalized definition of constrained dissipation, where the dynamical action of each system's dissipative channel can only happens when the other system is in a given quantum state [33]. Conditions that guarantee the "classicality" of the kinetic constraints is provided. In such a case, the system's reduced evolutions are defined by a Lindblad rate equation [34,35]. The entanglement generation is analyzed for two optical-like qubits systems whose individual decay dynamics can only happens when the other system is in the lower state. The entanglement is characterized both in the transitory and stationary regimes. In order to provide an deeper characterization of the dynamics, added to the entanglement behavior, we also study its relation with the quantum and classical correlations build up between both systems [36–40].

The paper is organized as follows. In Section 2 we provide a generalized definition of constrained dissipation for bipartite dynamics. Conditions that guarantee the classicality of the kinetic constraints is provided. In Section 3 we analyze the entanglement evolution for two optical-like qubits. In Section 4, the interplay between the constraints an local external fields that lead to a maximal entangled state is investigated. In Section 5 we provide the Conclusions. In the Appendix we briefly review the utilized entanglement measure as well as the definitions of quantum and classical correlations.

2. Constrained dissipation

We consider two systems A and B, both of them coupled to independent Markovian reservoirs. The dissipative Lindblad evolution [3] induced by each bath is denoted by $\mathcal{L}_A[\rho]$ and $\mathcal{L}_B[\rho]$. The bipartite density matrix describing both systems is $\rho_{AB}(t)$. In order to focus on the dissipative structure, we assume that both Lindblad superoperators commutate with their respective system unitary evolutions. Hence, in an interaction representation, the evolution of $\rho_{AB}(t)$ can be written as

$$\frac{d\rho_{AB}(t)}{dt} = \mathcal{L}_A[\rho_{AB}(t)] + \mathcal{L}_B[\rho_{AB}(t)]. \tag{1}$$

Each contribution is defined by the expressions

$$\mathcal{L}_A[\rho] = \frac{1}{2}\sum_i \gamma_A^i([A_i, \rho A_i^\dagger] + [A_i\rho, A_i^\dagger]), \tag{2a}$$

$$\mathcal{L}_B[\rho] = \frac{1}{2}\sum_i \gamma_B^i([B_i, \rho B_i^\dagger] + [B_i\rho, B_i^\dagger]), \tag{2b}$$

where $\{\gamma_A^i, \gamma_B^i\}$ are the dissipative rates of each dissipative channel defined by the operators $\{A_i, B_i\}$. In each sum, the index run from one up to the dimension of the system Hilbert space. For simplifying the notation, from now on we assume $\dim(\mathcal{H}_A) = \dim(\mathcal{H}_B)$.

The operators $\{A_i\}$ and $\{B_i\}$ only act, respectively, on the Hilbert space of system A and B. Hence, the bipartite evolution Eq. (1) is defined under the association

$$A_i \to A_i \otimes I_B, \qquad B_i \to I_A \otimes B_i. \tag{3}$$

The identity operators (I_A, I_B) indicates the absence of any correlation between the dynamics induced by each bath.

Constrained dissipation means that the action of each dissipative channel (operators A_i and B_i) only happen when the other system (B and A) is in a given subspace or quantum state. These kinetic constraints are introduced through the replacements

$$A_i \to A_i \otimes \mathcal{Q}_i, \qquad B_i \to \mathcal{P}_i \otimes B_i, \tag{4}$$