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# Measurement-induced disturbance and thermal negativity in 1D optical lattice chain

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## ABSTRACT

We study the measurement-induced disturbance (MID) in a 1D optical lattice chain with nonlinear coupling. Special attention is paid to the difference between the thermal entanglement and MID when considering the influences of the linear coupling constant, nonlinear coupling constant and external magnetic field. It is shown that MID is more robust than thermal entanglement against temperature  $T$  and external magnetic field  $B$ , and MID may reveal more properties about quantum correlations of the system, which can be seen from the point of view that MID can be nonzero when there is no thermal entanglement and MID can detect the critical point of quantum phase transition at finite temperature.

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## 1. Introduction

Quantum entanglement, as a strong nonclassical correlation between spatially separated quantum systems, has been playing a central role in quantum information processing [1]. It can be exploited to accomplish quantum teleportation, superdense coding, quantum cryptographic key distribution and so on [2]. However, recent studies show that entanglement does not account for all of the nonclassical properties of quantum correlations and is not the only type of quantum correlation that offers support for lots of quantum tasks. For example, some unentangled states are also useful for improving performance in some tasks of quantum computer [3]. So a natural question emerges whether there are other nonclassical correlations apart from entanglement or not. An answer to this

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question is quantum discord, which is built on the fact that two classical equivalent ways of defining the mutual information turn out to be inequivalent in the quantum domain, has been used to quantify all nonclassical correlations in a system, being the entanglement a particular case of it [4,5]. It is found that quantum discord provides a larger region of quantum states with nonclassical correlations, and a nonzero quantum discord but not entanglement may be responsible for the efficiency of a quantum computer [3,6]. Recently, numerous works have been devoted to the study of quantum discord [7–14]. However, due to the complicated optimization involved, it is usually intractable to calculate quantum discord analytically. Even for the two-qubit systems, the analytic of quantum discord can only be obtained for a few cases. Unlike quantum discord, Luo introduced a classical vs. quantum dichotomy in order to classify and quantify statistical correlations in bipartite states. They use measurement-induced disturbance (MID) to characterize correlations as classical or quantum [15]. The evaluation of MID does not involve optimization procedure, so MID is easier than quantum discord to denote quantum correlation, and it is desirable to investigate the relation among quantum discord, MID and entanglement.

It is well known that an important emerging field is the quantum entanglement in condensed matter systems such as spin chains. Accordingly several investigations of entanglement in thermal equilibrium states of spin chains subject to an external magnetic field at finite temperature have been made [16–20]. Quite recently, there are interesting works investigating the thermal quantum discord in different Heisenberg models [21–24]. It is shown that the behavior of thermal quantum discord differs in many unexpected ways from thermal entanglement, for example, the thermal quantum discord is more robust than thermal entanglement against temperature, since the quantum discord does not vanish at finite temperature, but thermal entanglement vanishes completely at a certain temperature. However, only spin-half systems were considered in previous studies as there exist concurrence [25] and quantum discord, which are good measures of entanglement and quantum correlation for spin-half system. Comparatively, there is currently an effort to study the comparison between quantum correlation and thermal entanglement in systems with higher spins. Motivated by this, in this paper, compared with the entanglement measured by negativity, we will study quantum correlation based on MID in spin 1 system, such as optical lattice chain. In comparison with the thermal quantum discord of two qubits [21–24], we not only expand the study on thermal quantum correlation to two qutrits, but also consider the effects of nonlinear coupling on thermal quantum correlation measured by MID. We find the nonlinear coupling brings different influences for entanglement and MID.

This paper is organized as follows. In Section 2, we give the model and calculate the density matrix for the spin 1 system. In Section 3, the effects of linear coupling constant  $J$ , constant  $K$  and external magnetic field  $B$  on the MID and thermal entanglement will be investigated at finite temperature. Finally, we conclude in Section 4.

## 2. The model Hamiltonian and the solutions

The development of laser cooling and trapping provides us more ways to control the atoms in traps, as a result, the system of atoms in optical lattice is among the promising candidates for quantum information processing [26,27]. Suppose there are two wells in the optical lattice with only one spin 1 atom trapped in each well. The lattice may be formed by three orthogonal laser beams, and we may use an effective Hamiltonian of the Bose–Hubbard form [28] to describe the system. For finite but small hopping term  $t$ , we can expand the Hamiltonian into powers of  $t$  and get [29]

$$H = J(\mathbf{S}_1 \cdot \mathbf{S}_2) + K(\mathbf{S}_1 \cdot \mathbf{S}_2)^2, \quad (1)$$

where  $J = -\frac{2t^2}{U_2}$ ,  $K = -\frac{2t^2}{3U_2} - \frac{4t^2}{3U_0}$  with  $t$  the hopping matrix elements, and  $U_s$  ( $s = 0, 2$ ) represents the Hubbard repulsion potential with total spin  $s$ , a potential  $U_s$  with  $s = 1$  is not allowed due to the identity of the bosons with one orbital state per well. When taking magnetic field along the  $z$ -direction into account, the effective Hamiltonian can be written as

$$H = J(\mathbf{S}_1 \cdot \mathbf{S}_2) + K(\mathbf{S}_1 \cdot \mathbf{S}_2)^2 + B(S_{1z} + S_{2z}), \quad (2)$$

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