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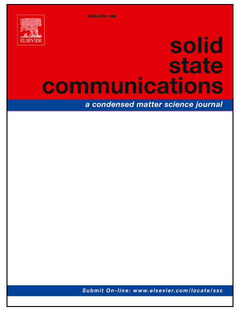

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Quantum Fisher information and the localization properties of two interacting particles in one-dimensional systems

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Abstract

The concept of quantum Fisher information (QFI) is used to characterize the localization properties of two interacting particles with on-site interaction on a one-dimensional lattice. It is found that the localization transition can be distinctively illustrated by the evolution of QFI if no inter-particle interaction is considered. For the two-particle system in a quasi-periodic potential chain, the interaction strength dependence of the QFI can be qualitatively different in the extended states and localized ones. For the two-particle system in a slowly varying potential lattice, the QFI decreases first and then increases with the interaction strength at all the states. In addition, the interaction induced localization effect can be revealed from the QFI spectra at different interactions in the two systems investigated here. The present work demonstrates that the QFI can well characterize the localization properties for the one dimensional two-particle systems with on-site interaction.

Keywords: A. Two-particle interacting system, D. Quantum Fisher information, D. Localization property

1. Introduction

The Anderson localization [1] is a well-known nontrivial quantum phenomenon induced by interference in disordered potentials. It was first observed for a single particle in one-dimensional ($1D$) lattice systems [2, 3]. Later on, the question on whether this localization effect operates in many-body interacting systems attracts much attention [4, 5]. Due to the complexity of many-body systems, researchers have subsequently investigated the localization properties of the two-particle systems [6, 7, 8, 9, 10, 11, 12, 13]. It was found that in the presence of disorder potentials, many-body interactions would lead to delocalization. Meanwhile, experiments on ultra-cold atoms have provided a powerful playground for the simulation of various condensed-matter systems and this allows us to check various critical issues that have been challenging. Some experiments did realize the quasi-periodic model in optical lattices and observed the localization transitions [14, 15], and thus have contributed substantially to the study about the interplay of localization and many body interactions.

On the other hand, Fisher information (FI) is a central concept in quantum estimation and quantum information theory [16, 17]. It gives the information about some system parameter we can achieve from a quantum state and thus brings rich fingerprints for evolutions and transitions. From another point of view, the FI characterizes the sensitivity of a state with respect to perturbation of the parameters. This means that we can obtain a higher estimation precision if FI is larger. Naturally, an extension of the FI to the quantum regime, i.e. the quantum Fisher information (QFI), allows a characterization of this information quantity to quantum systems [18, 19], which can be described by the quantum Cramér-Rao bound [16, 17, 20]. In general, to improve the precision, quantum resources such as coherence, entanglement, and so on, are used so that the quantum states of a system can be characterized and manipulated with high precision.

In recent years, the problem of QFI correlation and its signature at quantum phase transitions have been receiving substantial attention [21, 22, 23, 24, 25, 26, 27]. Our earlier work [26] tested and then approved the QFI as a signature to characterize the localization transition of several one-dimensional quantum models. In this work, we further explore the potential of QFI in characterizing the localization property and apply the concept of QFI to two-particle interacting systems. As the first step, it is of significance to address such systems in one-dimension ($1D$) quasi-periodic potential chain [28, 29] and slowly varying potential chain [3, 30]. It will be demonstrated that the QFI in characterizing these localization properties in such many-body systems is highly appreciated.

In fact, the localization properties of $1D$ two-particle systems have been studied by various methods such as Green function [31, 12, 32], transfer matrix [33], and especially quantum entanglement from the quantum information [34]. However, the QFI is a more intrinsic quantity in contrast to other correlation quantities. It is intimately related to the Shannon entropy [35] and Fubini-Study metric [36]. Moreover, the QFI can be used to describe the Heisenberg uncertainty relations [37] and classify and detect possible entangled states [38, 39]. In addition, the two-particle $1D$ system is more complex than one particle $1D$ system. On the whole, the application of QFI in such systems is significant in spite of being challenging. We expect it to be a

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