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The impact of the system parameters on the entanglement in spin chains coupled to the bosonic reservoir

ABSTRACT:

The presented work covers a study of selected models of spin chains, conducted to quantify the bipartite quantum entanglement between the spins of the system. At first, the entanglement is investigated in isolated systems prepared in the thermal equilibrium state. The subsequent analysis focuses on the changes in entanglement within open systems with hybrid dynamics of interaction with the environment. The chain itself is placed in the bosonic reservoir of a Markovian type, characterized by irreversible information loss from the system to the environment which describes the Lindblad equation. The spins of the chain, between which the entanglement is not considered, are treated as a non-Markovian environment and "excluded" from the analysis by reducing the density matrix. The mean of expressing the entanglement strength in the considered systems is the concurrence, defined by Wooters and Hill. The calculations required to prepare the following dissertation are done numerically, using the authorial procedures settled on the Runge - Kutta method of the sixth order, used for iterative solving the Lindblad equation. Based on the preliminary analysis of the forms of Lindblad equation's solutions and obtained numerical results, the following conclusions are drawn: the most beneficial conditions for large entanglement in isolated spin chains are observed for shorter chains, possibly of even numbers of spins. In materials described by XXX Heisenberg model prepared in a thermal equilibrium state, negative exchange integral with high absolute value is preferable for the system to exhibit high entanglement; for XXZ exchange interaction model, the same fact holds for Jz integral, for Jx integral, however, the sign does not matter, only its absolute value - the higher it is, the higher is the entanglement. For XYZ Heisenberg model, this relation is more complicated. Yet, it can be stated that for evenly numbered spin chains, the product of exchange integrals for all perpendicular directions should be negative. The uniform magnetic field mostly negatively impacts the entanglement, except for a small field for short spin chains of an odd number of spins. The non-uniform magnetic field can enhance the low entanglement; however, it reduces the entanglement in systems with its high initial value in a thermal state. Dzyaloshinskii - Moriya type of superexchange interaction has a slightly negative effect on the entanglement in most of the analysed systems; Kaplan - Shekhtman - Entin - Wohlman - Aharony exchange slightly enhances high entanglement in chains with an odd number of spins, but reduces low entanglement for the same chains. Finally, three-spin interactions prove to have a positive impact on the entanglement in chains with odd cardinality. Analysis of time evolution for spin chains in the Markovian bosonic environment led to the following observations. For only exchange interaction taken into consideration, the most robust to decoherence turned out to be the states in which $|Jz| < Jx$. A magnetic field constant in time has no impact on entanglement loss; a time-dependent field raises the entanglement only in shorter spin chains, and this effect can be benefitted only if one adapts the frequency of field changes to the number of spin excitations in the initial state. Dzyaloshinskii - Moriya and Kaplan - Shekhtman - Entin - Wohlman - Aharony interactions have almost only a negative impact on the entanglement, while three spin interaction is advantageous for short chains; in longer chains, its effect becomes negative.