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Reducing resources for quantum simulation by leveraging entanglement measures

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Among the different approaches to studying the structure of atomic nuclei comprising protons and neutrons, the nuclear shell model formalism is widely successful across different regions of the nuclear chart. However, applying the shell model formalism becomes difficult for heavier mass regions, as the Hilbert space needed to define such a problem scales exponentially with increasing number of nucleons. Quantum computing is a promising way to deal with such a scenario, however for systems of practical relevance the amount of quantum resources required is beyond the capabilities of today's hardware. Quantum entanglement provides a distinctive viewpoint into the fundamental structure of strongly correlated systems, including atomic nuclei. There is a growing interest in understanding the entanglement structure of nuclear systems, and leveraging this knowledge to simulate many-nucleon systems more efficiently.

In this work, we apply entanglement measures to reduce the quantum resources required to simulate a nuclear many-body system. We calculated the single orbital entropies as more neutrons were added for selected p-shell (Z = 2, 3, and 4) nuclei within the nuclear shell model formalism. In the case of the Li (Z = 3) isotopic chain, the proton single orbital entanglement of the 0p1/2 orbital in ^{6}Li (1+) is 1.7 times more than ^{7}Li (3/2-) and ^{8}Li (2+). Also, the single orbital entanglement of proton 0p1/2 in ^{9}Li (3/2-) is five times less than that of ^{6}Li (1+). Hence, if the less entangled orbitals are treated differently, more efficient simulation circuits with fewer qubits and fewer quantum gates are possible for nuclei like ^{9}Li (3/2-). Moreover, other entanglement metrics like mutual information can provide valuable insight into the underlying structure of a few-nucleon system. This method of reducing quantum resources could be useful for other neutron-rich nuclei of different isotopic chains.

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quantum computing

Keyword-2

nuclear theory

Keyword-3

quantum simulation

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