Quantum Information Science on the Intersections of Nuclear and AMO Physics

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Enhancing Quantum Utility: simulating large-scale quantum spin chains on superconducting quantum computers (25+5)

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We present the quantum simulation of the frustrated quantum spin-1/2 antiferromagnetic Heisenberg spin chain with competing nearest-neighbor (⊠1) and next-nearest-neighbor (⊠2) exchange interactions in the real superconducting quantum computer with qubits ranging up to 100. In particular, we implement the Hamiltonian with the next-nearest neighbor exchange interaction in conjunction with the nearest-neighbor interaction on IBM's superconducting quantum computer and carry out the time evolution of the spin chain by employing the first-order Trotterization. Furthermore, our implementation of the second-order Trotterization for the isotropic Heisenberg spin chain, involving only nearest-neighbor exchange interaction, enables precise measurement of the expectation values of staggered magnetization observable across a range of up to 100 qubits. Notably, in both cases, our approach results in a constant circuit depth in each Trotter step, independent of the number of qubits. Our demonstration of the accurate measurement of expectation values for the large-scale quantum system using superconducting quantum computers designates the quantum utility of these devices for investigating various properties of many-body quantum systems. This will be a stepping stone to achieving the quantum advantage over classical ones in simulating quantum systems before the fault tolerance quantum era.

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