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Simulating three-wave interactions on quantum computers[1]

YUAN SHI[2], Lawrence Livermore Natl Lab — Quantum computing may lead to game-changing capabilities for plasma physics. However, plasmas are usually considered classical, and exactly how quantum systems can be used to solve plasma problems remains an open question. Moreover, many problems in plasma physics are nonlinear, whereas quantum computers are designed to carry out unitary evolution in Hilbert space, which is fundamentally linear. In this invited talk, we overcome these difficulties and present the first results using real quantum hardware to simulate nonlinear three-wave problems. First, a generally applicable algorithm is derived, which decomposes the Hilbert space into a direct sum of finite-dimensional subspaces. Within each subspace, the nonlinear three-wave problem is mapped to a tridiagonal Hamiltonian problem, which achieves effective three-wave interactions even when the hardware has no native cubic coupling. Second, the algorithm is implemented on quantum hardware using both digital and analog approaches. In the digital approach, the computation is carried out using a sequence of native gates. Using two qubits on state-of-the-art quantum cloud services, ~20 native gates are needed to approximate a single simulation step, which can then be repeated ~10 times before results are corrupted by decoherence. Alternatively, in the analog approach, the Hamiltonian evolution is realized by driving the quantum hardware with an optimized control pulse. High-fidelity results are obtained for ~100 three-wave gate repetitions using the lowest three levels of a transmon qudit. Without expensive optimization, reliable control pulses may also be synthesized cheaply using interpolation when parameters of the Hamiltonian vary. Our results highlight the advantage of using customized gates on noisy intermediate-scale quantum computers. The generalized multi-wave gates are potentially useful building blocks for computing a large class of problems in plasma physics.

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