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Evaluating the neutron drip line using quantum computing

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An understanding of the properties and behaviour of neutron-rich nuclei is essential in the study of phenomena such as neutron stars and supernovae. Successive addition of neutrons to an atomic nucleus yields isotopes that may or may not be stable: past a certain point, a nucleus experiences a decay process in which it leaks out neutrons, known as a neutron drip line. For nearly 20 years, the largest nucleus for which this was observed experimentally is Oxygen; its heaviest bound isotope is ^{24}O, and it is confirmed that ^{26}O and ^{28}O are unbound. A breakthrough in 2019 resulted in experimental confirmation of drip lines for isotopes of Fluorine and Neon. However, results for elements higher in the nuclear chart remain unknown and unverified in either experiment, or even theory, due to the computationally complex nature of the problem.

Quantum computing has the potential to solve problems in the physical sciences more efficiently. While it has been widely applied to quantum chemistry, there are relatively fewer applications in nuclear physics. In this work, we extend the study of Oxygen to heavier isotopes than have been explored previously in order to demonstrate the neutron drip line using quantum computing. We begin using a basic 12-qubit variational eigensolver on a quantum simulator, and develop highly-optimized quantum circuits for this purpose. We evaluate the ground state energies using both phenomenological interactions and recently-developed microscopic interactions for which the drip line has been observed to closely match experimental results. Then, we leverage symmetries to reduce the problem to a 5-qubit one which is suitable for execution on real quantum hardware, and discuss the prospects of doing so. Such a demonstration shows how, with suitable resource management and leveraging key properties of the system, quantum computing may soon enable us to explore systems beyond the reach of both contemporary nuclear theory and experiment.

Keyword-1

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Keyword-2

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Keyword-3

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