Noise-robust energy estimates from deep circuits on real quantum computer hardware

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A key question regarding the future of quantum computing is that of "useful quantum advantage" - i.e., when will we start to see the advantage of using quantum computers over classical methods to solve problems with some practical application? The Variational Quantum Eigensolver (VQE) [1], a quantum algorithm for solving ground state energy problems, is currently the most promising candidate for achieving this milestone in the near term, however the level of noise on present day quantum hardware has so far prohibited the application of VQE to any classically intractable problems. The recently introduced Quantum Computed Moments (QCM) [2, 3] method, based on Lanczos expansion theory [4, 5, 6], offers a way of obtaining corrections to variational estimates which, on relatively shallow-depth trial-state circuits considered to date, display a high degree of robustness to quantum logic errors. On real quantum computer hardware we explore this robustness by applying the QCM approach to problems in quantum magnetism of up to 20 qubits with trial-state circuits of increasing depth and complexity (up to $\sim$500 CNOTs). We find that the error robustness of the QCM estimates persist, well into the deep trial-state circuit region where errors overwhelm the VQE results. We perform a theoretical analysis of the QCM method under various noise models to explain this striking robustness phenomenon. Across the ensemble of cases studied, in the intermediate circuit depth regime, the QCM estimate offers a meaningful energy estimate and may point the way to a useful quantum heuristic approach to these problems.

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