Abstract Submitted
for the MAR16 Meeting of
The American Physical Society

A universal fault-tolerant gate set for the 5-qubit quantum code THEODORE YODER, RYUJI TAKAGI, ISAAC CHUANG, Massachusetts Institute of Technology — While the smallest single-error correcting classical code encodes one bit in just three, the smallest such quantum code requires five qubits to protect one qubit. Yet, the 5-qubit quantum code is widely regarded as useless when it comes to encoded quantum computation, as it supports just one non-Pauli transversal gate, the $K = SH$ gate where H is Hadamard and S is the phase gate. However, transversal gates, though convenient, are not all there is to fault-tolerant computation. Here we develop non-transversal, fault-tolerant logical gates for the 5-qubit quantum code, including logical controlled-Z (CZ) and logical controlled-controlled-Z (CCZ). With K, we can then create fault-tolerant CNOT and Toffoli gates. Together, logical Toffoli and K imply that the 5-qubit code is capable of universal, fault-tolerant quantum computation. Moreover, we achieve our results without magic states. Indeed, no ancillary qubits beyond those needed for error-correction are necessary in any of our fault-tolerant constructions. We also report fault-tolerance thresholds for our new gates, calculated by exact computer simulation. In some cases, our logical gates on the 5-qubit code have better thresholds than the analogous constructions on the next smallest quantum code, the 7-qubit code.

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Date submitted: 06 Nov 2015 Electronic form version 1.4