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The generalised semi-Clifford conjecture is false

The Clifford hierarchy is a nested sequence of sets of quantum gates that can be fault-tolerantly performed using gate teleportation within standard quantum error correction schemes. The importance of these gates has motivated numerous studies of their structure. Zeng-Chen-Chuang conjectured in 2007 that all hierarchy gates are generalised semi-Clifford, i.e. take the form $C_1 \Pi D C_2$ for Clifford gates C_1, C_2, a permutation gate Π, and a diagonal gate D; Beigi-Shor proved in 2008 that this holds for all third-level gates.

We construct a five-qubit gate that is in the fifth level of the Clifford hierarchy but is not generalised semi-Clifford. Rather than simply present and verify our counterexample to the generalised semi-Clifford conjecture, we show how its form can be deduced. Our counterexample also demonstrates that the Clifford hierarchy is not closed under inverses.

(Joint work with Oscar Lautsch.)