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Nonlocal Games in the High-Noise Regime: Optimal Quantum Values and Rigidity

Self-testing is a key characteristic of certain nonlocal games, which allow one to uniquely determine the underlying quantum state and measurement operators used by the players, based solely on their observed input-output correlations. Motivated by the limitations of current quantum devices, we study self-testing in the high-noise regime, where the two players are restricted to sharing many copies of a noisy entangled state with an arbitrary constant noise rate. In this setting, many existing self-tests fail to certify any nontrivial structure. We first characterize the maximal winning probabilities of the CHSH game, the Magic Square game, and the 2-out-of-n versions of these two games as functions of the noise rate. These results enable the construction of device-independent protocols for estimating the noise rate. Building on this analysis, we show that these games can self-test one, two, and n pairs of anticommuting Pauli operators, respectively. These are the first known self-tests that are robust in the high-noise regime and remain sound even when the players' measurements are noisy. Our proofs rely on Sum-of-Squares (SoS) decompositions and Pauli analysis techniques developed in the contexts of quantum proof systems and quantum learning theory.