Finding hidden entanglement

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Quantum information applications usually require entanglement in the form of pure maximally entangled pairs. In general, however, states can be in incoherent mixtures of pure states. A state is said to be distillable if any maximally entangled singlets can be extracted from it, using only local operations and classical communication. In Hilbert spaces larger than 2x3, there are now known to exist entangled states from which no maximally entangled pairs can be distilled – such states are called bound entangled [1] and have recently been observed in the laboratory using trapped ions [2] and linear optics [3]. The "Smolin state" [4] is a particularly curious example; for example, it maximally violates a certain class of Bell inequalities [5], which is surprising, since one might naively expect that maximal demonstrations of quantum nonlocality would occur for pure quantum states, i.e., states with zero entropy. Also, the Smolin state has the interesting property that it can be distilled when a single party has possession of more than one of the four qubits.

The Smolin state is the incoherent sum of four 4-qubit states, each of which is the tensor product of two maximally entangled Bell states. To create it, we use spontaneous parametric down-conversion to produce photons pairs that are simultaneously entangled ("hyper-entangled" [6]) in polarization and spatial mode. By combining the results of four simultaneous but incoherent processes, we are able to realize the desired state, which we can then characterize by quantum state tomography. An important feature of our bound entanglement source is that it is tunable: we can easily vary the coherence between the different creation processes, or add noise to the state, and thus observe transitions between regions of bipartite entanglement, multipartite entanglement, bound entanglement, and full separability.

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