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Entanglement Entropy in Conventional and Topological Orders

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Exotic phenomena in quantum many-body systems are accompanied by non-trivial patterns of entanglement in ground-state wave functions. One useful measure of entanglement for a many-body state is the entanglement entropy (EE) between a part Ω of the system and the rest $\bar{\Omega}$. For a system with short-range correlations only, Ω and $\bar{\Omega}$ correlate only in the vicinity of the boundary separating them and the EE scales with the size of the boundary (so called, boundary law). Here we demonstrate that there appear two types of additional constant contributions to the EE which can be used as useful fingerprints of conventional and topological orders, respectively.
For a two-dimensional system with topological order, the additional constant, dubbed topological entropy, takes on a universal value reflecting the underlying gauge theory, as originally proposed by Kitaev and Preskill and by Levin and Wen. As a step beyond the simple solvable models considered in their original papers, we take as an example the quantum dimer model on the triangular lattice, and examine the robustness of the proposal in a system with finite correlation length. We demonstrate numerically that the topological entropy can indeed be detected in our example and takes on a value reflecting the underlying Z_2 gauge theory.
In a system with conventional order associated with spontaneous symmetry breaking, there appear degenerate ground states corresponding to different ordering textures. In a finite-size system, the degeneracy is slightly split, and we have a set of nearly-degenerate symmetric ground states which can be approximated by a linear superposition of ordered states. We argue that this structure of ground-state wave function, reminiscent of the cat state $|000\ldots\rangle + |111\ldots\rangle$, gives a positive contribution $\ln d$ to EE, with d being the ground-state degeneracy. We propose this as a useful signal of symmetry breaking, and provide some numerical demonstrations in the antiferromagnetic XXZ chain and in the frustrated J_1-J_2 chain, based on exact diagonalization and recently proposed iTEBD algorithm.