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Entanglement Entropy of States with Long-Range Magnetic Order

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We study the bipartite entanglement entropy of spin models whose ground states have perfect ferromagnetic (FM) or antiferromagnetic (AFM) long-range order. For the FM case the entanglement entropy is taken to be one-half the quantum mutual information so as to properly take into account the ground state degeneracy. The calculation of the entropy for this case is then straightforward and agrees with previous work using a different approach. For the AFM case the problem is reduced to that of four coupled spins. This simplification allows us to determine the asymptotic behavior of the entropy analytically with results which agree well with exact numerical calculations. In both the FM and AFM cases we find the entropy grows logarithmically with block size, N_1. For example, if we take $N_1 = N/2$, where N is the total number of spins, then in the FM case the entropy, E, scales as $E \simeq \frac{1}{2} \ln N_1$, and in the AFM case, $E \simeq \ln N_1$. In both cases the area law is clearly violated. Implications of these results for more general states with long range order are also discussed.

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