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Topological phases and superconducting states in Kitaev-like lattice models

Topological field theories can be realized as topological phases in certain integrable models and two-dimensional strongly-correlated condensed matter systems. We particularly focus on the Kitaev honeycomb lattice model that exhibits the Abelian doubled-Z_2 and the non-Abelian Ising topological phases. Quasiparticle excitations of these phases have attracted considerable attention recently both for fundamental reasons as a system with non-Abelian fractional statistics and for potential applications in topological quantum computation.

We present an exact solution of the Kitaev spin model on the honeycomb lattice. We employ a Jordan-Wigner type fermionization and find that the Hamiltonian takes a Bardeen-Cooper-Schrieffer (BCS) type form, allowing the system to be solved by Bogoliubov transformation. Our fermionization does not employ non-physical auxiliary degrees of freedom and the eigenstates we obtain are completely explicit in terms of the spin variables. The ground-state is obtained as a BCS condensate of fermion pairs over a vacuum state which corresponds to the toric code state with the same vorticity. We show in detail how to calculate all eigenstates and eigenvalues of the model on the torus. In particular, we find that the topological degeneracy on the torus descends directly from that of the toric code, which now supplies four vacua for the fermions, one for each choice of periodic vs. anti-periodic boundary conditions. The reduction of the degeneracy in the non-Abelian phase of the model is seen to be due to the vanishing of one of the corresponding candidate BCS ground-states in that phase. This occurs in particular in the fully periodic vortex-free sector. The true ground-state in this sector is exhibited and shown to be gapped away from the three partially anti-periodic ground-states whenever the non-Abelian topological phase is gapped. The exact solution of the related star lattice chiral spin liquid is also presented.

This is a joint work with Graham Kells and Joost Slingerland.

References

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