Disorder in an exactly solvable quantum spin liquid

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Abstract

We investigate the properties of the Kitaev honeycomb model with both site dilution and exchange randomness. Embarking on this work, we review disorder in some strongly correlated electron systems, including spin-$\frac{1}{2}$ and spin-1 Heisenberg antiferromagnetic chains, two dimensional Heisenberg antiferromagnets, the cuprates and graphene. We outline some aspects of resonating valence bond phases, valence bond solids, spin liquids and quantum computation that are pertinent to an understanding of the Kitaev model. The properties of the Kitaev model without disorder are discussed and it is found to be a critical spin liquid, with algebraic correlations in two spin operators $\sigma_i^\alpha \sigma_j^\alpha$, where i and j are either end of a link of type $\alpha = x, y$ or z on the honeycomb lattice.

The Kitaev model is exactly solvable and we show that this remains so in the presence of site dilution and exchange randomness. We find that vacancies bind a flux. In the gapped phase, a vacancy forms an effective paramagnetic moment. With two or more vacancies we describe the interaction of their effective moments and show that a finite density of vacancies leads to a divergent macroscopic susceptibility at small fields.

In the gapless phase the effective moment has a susceptibility that is, to leading order at small fields, $\chi(h) \sim \log(1/h)$. Interaction between the moments from two vacancies on opposite sublattices cuts off this divergence in susceptibility at a large but finite constant. Two vacancies on the same sublattice behave quite differently and we find the combined susceptibility is parametrically larger than that of an isolated vacancy, $\chi(h) \sim [h(\log(1/h))^{3/2}]^{-1}$.

We also investigate the effects of slowly varying, quenched disorder in exchange coupling. We demonstrate that this does not qualitatively affect the susceptibility but show that the heat capacity $C \sim T^{2/z}$, where z is a measure of the disorder and increases from one with increasing disorder strength.