Valence-bond Theory for Highly Disordered Quantum Antiferromagnets

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Introduction

In this work [1] we present a large-N variational approach to the Bhatt-Lee [2] problem describing the magnetism of insulating doped semiconductors (DS), based on a disorder-generalization of the resonating-valence-bond theory for quantum antiferromagnets. This method is shown to capture all the qualitative and even quantitative predictions of the strong-disorder renormalization group approach over the entire experimentally relevant energy range. The simplicity of this method allows for an essentially exact analytic solution of the variational problem without any adjustable parameters, by mapping the problem to that of a hard-sphere fluid with an energy (length scale) dependent core diameter.

Results and Discussion

We start with an appropriate two-orbital *t-J* model. For the insulating uncompensated DS, electrons become Mott localized on singly-occupied impurity state, resulting in an effective Heisenberg spin system with the inter-site AF coupling falls off exponentially with distance. The magnetic susceptibility, shown in Figure 1, is calculated by the variational large-*N* theory. Owing to the broad distribution of exchange coupling in the presence of strong positional disorder, the large-*N* ground state is essentially a random singlet state with no resonance between the valence bonds (VB). This fact allows us to state a geometric decimation procedure for the large-*N* solution by iteratively remove (form inert VB singlet) the strongly coupled spin pair, or equivalently, the shortest one. The magnetic susceptibility (Fig. 1) is readily given by the density of free (undecimated) spins. The simplicity of this method allows for an accurate close-form analytic solution of the variational large-*N* problem without any adjustable parameters, by mapping the problem to that of a hard-sphere fluid with an energy (length scale) dependent core diameter.

Conclusions

We have shown that a variational large-*N* method provides a physically transparent and quantitatively accurate description of inter-site spin correlations on the insulating side of DS. In the presence of strong positional disorder, each localized spin forms a VB singlet with a rather uniquely defined partner, allowing for a closed-form solution of the problem in the large-*N* limit. Even more importantly, this approach opens a very attractive avenue to describe the behavior across the MIT by examining the two-orbital *t-J* model with finite inter-site hoppings. Similarly as in the large-*N* solution of the two-impurity Kondo problem [3], we expect Kondo-screened sites to contribute to the formation of a coherent Fermi liquid, while VB singlet pairs to "drop out" from the conduction sea and remain Mott localized. Such gradual conversion of the correlated electron fluid into a localized VB solid may provide a microscopic underpinning for the phenomenological "two-fluid" model – possibly the key missing link for cracking the MIT in doped semiconductors.

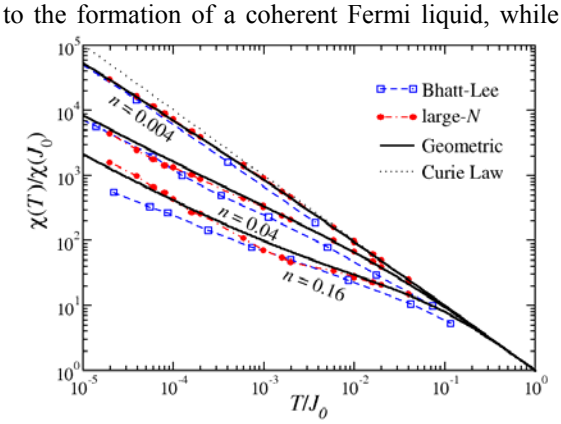

Figure 1: Normalized magnetic susceptibility of highly disordered 3D Heisenberg magnets evaluated with the Bhatt-Lee method, the large-N self-consistent theory, and the geometric decimation procedure at doping concentrations $n = \frac{4\pi}{3}\rho_0 a^3 = 0.004$, 0.04, and 0.16.

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References

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