MAGNETIC EXCITATIONS IN RANDOM MAGNETIC CHAINS IN THE LARGE-S LIMIT

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Abstract

Harmonic magnon modes in random-exchange and random-field Heisenberg chains are studied in the large spin limit. In the weak disorder limit, the integrated density of states and inverse localization length for the low energy excitations in random fields is computed using the Coherent Potential Approximation (CPA); in the case of random exchange systems, the corresponding calculation is carried out using the Coherent Exchange Approximation (CAE). These results are compared with numerical and exact perturbation results obtained for various disordered systems and with renormalization group studies made for the same systems. Good agreement is obtained; in particular, the anomalous power-law behavior is reproduced. Developing a phenomenological model, we are able to find the density of states for asymmetric distributions of the exchange interactions. We also present a thermodynamic study of the random exchange model and compare our results with those for the corresponding spin-1/2 chain. Finally, we briefly present our analytical solution of the CPA self consistent equation which eliminates the errors associated with the numerical solution of the equation.

1. Introduction

Determining the properties of magnetic excitations and the ground state of a random magnetic chains is still an intriguing problem. Magnetic chains have also interesting connections to other disordered systems. The effect of the disorder on the distributions and the localization of the low energy modes of spin excitations are studied by linearizing the equation of motion of the spins about the classical ground state using the renormalization group technique [1] and the effective medium approximations as well as numerical analysis [2]. We investigated the energy dependence of density of states and the localization length (a distance over which the amplitude of the excitation has an appreciable value.) We present our results for two systems: first, Heisenberg ferromagnetic (FM) chain in random weak field and second, random exchange

Heisenberg spin glass in zero field. Both systems is assumed to have nearest neighbor interactions and common complicated features.

2. Calculations

The spin equation of motion for a random weak field \([1,2]\) is

\[
(2 + \zeta_n h - w)S^+_n = S^+_n - 1 + S^+_n + 1 ,
\]

where \(\zeta_n = \pm 1\) with equal probability, \(h\) is the strength of the random field, \(S^+_n\) is the spin raising operator, \(w\) is the energy and \(n\) is the site index. The corresponding equation of motion for the spin glass in zero field is similar to equation (1) by replacing \(w \rightarrow \zeta_n w\) [2] where

\[
\zeta_n = \prod_{1=1}^{n} J_{1,1+1} .
\]

\(J_{1,1+1}\) is the nearest neighbor exchange interactions independently distributed random variable. The behavior of the random field system is determined by the battle between the FM exchange interaction \(J\) and random field \(h\). In low dimensions, the FM ground state is unstable against the overturning of spin droplets, however for very weak field, there is an effective FM ground state for length scales longer than harmonic magnon wavelength [1] that is, \(k^{-1} < 2J/h\) (for weak field this criterion can be realized.) Thus we can calculate the spectrum using the Coherent Potential Approximation (CPA). The CPA is useful if ground state is known and the coherent field—describing the random medium on the mean field level—can be obtained by setting the average scattering matrix zero [2]. For uniform mode (\(k = 0\)), the CPA results for integrated density of states (IDOS) and the inverse localization length \(\lambda\) (for symmetric distributions of random field) are [2]

\[
\text{IDOS} = \pi^{-1} 2^{-5/6} \sin \left( \frac{5\pi}{3} \right) h^{2/3} ,
\]

\[
\lambda = 2^{-5/6} \cos \left( \frac{5\pi}{3} \right) h^{2/3} .
\]

Equation (1) is analogous to electronic problem by identifying corresponding random potential [3] in the tight binding Hamiltonian. For uniform mode, the random potential is \(V_n = -\zeta_n h\). Whereas for the spin glass the random potential is \(V_n = \zeta_n w\) where equation (2) is used for the random coefficient [2]. For this case, the coherent exchange is applicable [2]. Derrida and Gardner performed [4] exact perturbation calculation for