RKKY Interactions in the Regime of Strong Localization

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Introduction

The presence of weak disorder is not expected to lead to any significant changes in the physical properties which are dominated by the RKKY interactions[1]. In the presence of stronger disorder, however, probability distribution of the RKKY interactions becomes broad, and the typical interaction strength cannot be well characterized by its variance [2]. Within an Anderson insulator the electrons are bound to impurities, and thus can hardly be expected to generate the long-range part of the RKKY interaction. How can we have at the same time large moments of the distribution of RKKY interactions, along with its fast decay with the distance? This is an important physical question that we resolve in our work [3].

Results and Discussion

We numerically study the distribution of the RKKY interactions within the Anderson insulator phase. We find that in presence of strong disorder and localization, the distribution function develops a strongly non-Gaussian form featuring long tails, Figure 1. In such a case, the even moments of the distribution assume very large values, while at the same time a typical width of the distribution remains very small. Instead of the arithmetic average (i.e. standard deviation of the distribution) we find that the *typical* value of the interaction is better characterized by the geometric average of the distribution, $I_{typ}(R) \equiv \exp < \ln |I(R)| >$. We find that this quantity is exponentially suppressed in the presence of Anderson localization, explaining how the long-range part of the RKKY interaction is suppressed.

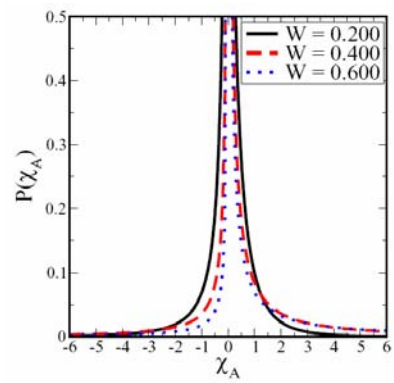

Figure 1: Scaled distribution of the RKKY interactions, $\chi_A(R) = \mathrm{Re}^{R/\xi}\,\chi(R)$, for several disorder strengths. (ξ is the localization length.)

Conclusions

Our results portray an interesting physical picture with potentially far-reaching consequences. In the metallic regime the RKKY interactions remain long-ranged even in presence of weak disorder, and in this regime one may expect a well developed collective behavior of the spin system, leading to magnetic ordering at low temperature. When the Anderson localized regime is approached, the RKKY interaction between a typical pair of distant spins is significantly suppressed or even negligibly small. Very occasionally, a pair of distant spins will interact strongly, due to rare disorder configurations producing long tails in the distribution function. If the resulting RKKY interaction is antiferromagnetic, then such a pair can be expected to lock in a tightly bound singlet -- thus forming an essentially inert molecule that practically detaches from the rest of the spin system. Alternatively, a ferromagnetic interaction will lead to the formation of a bound triplet state. It is interesting to note a degree of asymmetry of the distribution of the RKKY interactions, that we have found at strong disorder. This finding seems to indicate that ferromagnetic correlations may effectively compete with the tendency for singlet formation, possibly leading to nano-scale ferromagnetism coexisting with a random singlet phase.

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