GAPPED ITINERANT SPIN EXCITATIONS ACCOUNT FOR MISSING ENTROPY IN THE HIDDEN ORDER STATE OF URu_2Si_2

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Introduction

Heavy fermion metals – compounds which have high effective electron masses due to many body effects – represent a class of materials with exotic properties, such as unusual magnetism, unconventional superconductivity, and "hidden order" parameters. The heavy fermion superconductor URu_2Si_2 has held the attention of physicists for the past two decades due to the presence of a "hidden order" phase beneath 17.5 K. Neutron scattering measurements indicate that the ordered moment is 0.03 μ_B, much too small to account for the large heat capacity anomaly at 17.5 K.

Results and Discussion

We present recent neutron scattering experiments which unveil a new piece of this puzzle – the spin excitation spectrum above 17.5 K exhibits well-correlated itinerant-like excitations up to at least 10 meV emanating from incommensurate wavevectors. In figure 1, the spin excitation spectrum is shown in the hidden order state, demonstrating the gaps at ~ 2 meV at the zone center (1,0,0), and ~ 4 meV at the incommensurate points (1±0.4,0,0). The temperature dependence of a point at 0.25 meV energy transfer and (0.6,0,0) is shown in the inset. The gap closes at the transition temperature of 17.5 K. Figure 2 shows the excitation spectrum at 20 K. Note the presence of ungapped excitations with a high group velocity - these are itinerant-like spin fluctuations. The fit in the lower panel to the Chou model (used for paramagnons in the cuprates) can be used to extract a characteristic spin-wave velocity of 45(10) meV Å and a correlation length of 14(2) Å. These parameters were then used to calculate the contribution to the heat capacity above the hidden order transition, which has a linear temperature dependence due to the topology of the excitations. The value obtained of $\gamma = 220(70)$ mJ/mol K^2 is in good agreement with bulk measurements of the electronic specific heat at 20 K. The loss of these spin excitations through the transition temperature explains the reduction in the electronic specific heat (γ) through the transition.

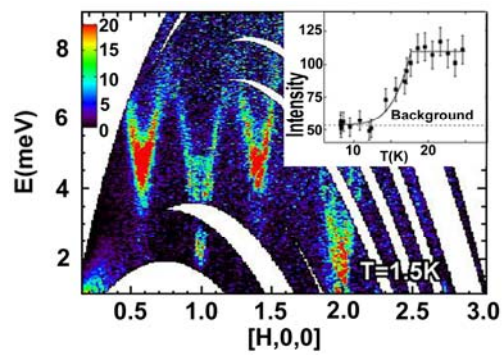

Fig. 1 Inelastic neutron scattering (INS) dispersion curve of URu_2Si_2 at 1.5 K in the (H,0,0) direction. Note the gapped spin wave spectrum. The inset shows the intensity at 0.25 meV at (0.6,0,0), illustrating the closing of the gap.

Conclusions

The gapping of spin excitations clears up a 20 year old mystery concerning the change in the electronic specific heat at the transition. However, an order parameter has still not been identified. A new theory for hidden order must account for these itinerant like excitations and the lack of crystal fields up to at least 10 meV.

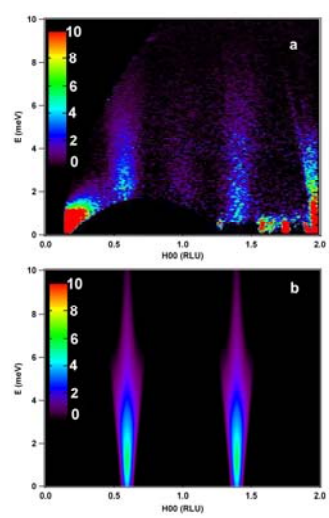

Fig. 2 (a) INS of URu_2Si_2 at 20 K (b) Calculation based upon the Chou model

Acknowledgements

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References

[1] C. Broholm *et al*., Phys. Rev. B, **43**, 12809 (1991).
[2] H. Chou *et al*., Phys. Rev. B, **43**, 5554 (1991).
[3] C. R. Wiebe *et al*., Nature Physics, accepted for publication (2006).