Novel Magnetic States in the Heavy-Fermion Quantum-Critical Material $CeRhIn_5$ at High Magnetic Fields Studied by NMR

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Introduction

As a continuous phase transition, such as spin-density order, is tuned toward zero temperature by doping, pressure, or magnetic field, physical properties are controlled by quantum fluctuations of the order parameter. Because only bosonic degrees-of-freedom become critical in this conventional model of a quantum-phase transition (QPT) [1], the Fermi surface evolves smoothing through it. Although this conventional picture accounts for aspects of some systems around a QPT, it fails to capture properties of the much-studied heavy-fermion materials $CeCu_{6-x}Au_x$ or $YbRh_2Si_2$ [2] at their QPTs. Motivated by this failure of the conventional model, theory has suggested that fermionic as well as bosonic degrees-of-freedom may be critical, which produces not only an observed jump in Fermi volume at the QPT but also energy/temperature scaling in these heavy-fermion systems [3]. Perhaps, the most striking support of this theory is the direct observation by dHvA of an abrupt increase in Fermi volume at the pressure-tuned QPT of the heavy-fermion antiferromagnet $CeRhIn_5$ [4]. This jump signals a localized to delocalized change in the 4f-electron configuration. Recently, dHvA studies at the NHMFL Tallahassee and Los Alamos discovered evidence for a field-tuned QPT in $CeRhIn_5$ at atmospheric pressure as well as a reconstruction of the Fermi surface within the magnetically ordered phase below the field-induced QPT [5]. The field- and pressure-tuned quantum (T=0) phase boundaries in $CeRhIn_5$ agree well with theoretical predictions. However, the microscopic magnetic properties of antiferromagnetic phases with large and small Fermi surfaces are not understood but essential to a validation of theory.

Experimental

The spin susceptibility and magnitude of the ordered moment in $CeRhIn_5$ can be probed through the Knight shifts as a splitting or shift of the NMR spectrum. In addition to changes in the Fermi surface at high magnetic field (near 30 T) for $H_0||ab$, neutron scattering has found a transition from incommensurate magnetic order (1/2, 1/2, .297) to commensurate magnetic order (1/2, 1/2, 1/4) at a magnetic field of 2 T [6]. However, for $H_0||c$, the magnetic states has yet to be determined. As an initial experiment, the magnetic order with $H_0||c$ has been determined up to 30 T in the Cell 2 high homogeneity resistive magnet and 17 T superconducting magnet.

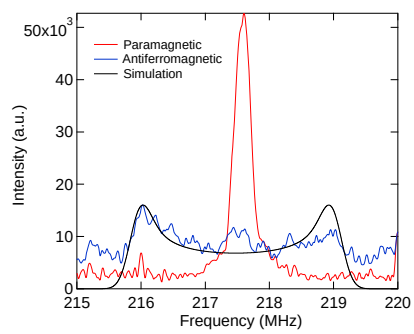

Fig.1 Paramagnetic, antiferromagnetic, and simulated spectrum for $CeRhIn_5$ at H_0 = 23 T.

Results and Discussion

Both paramagnetic (above T_N ~ 3.8 K) and antiferromagnetic NMR spectra have been measured in a range of applied fields and temperatures. We have found that the magnetic structure for $H_0||c$ remains incommensurate up to H_0 = 30 T whereas for $H_0||ab$ the magnetic structure changes to commensurate at H_0 = 2 T, the latter having been initially determined by neutron scattering. These results elucidate the anisotropy of the field dependent magnetic ordering in $CeRhIn_5$ and provide an initial step for experiments in higher magnetic field to clarify the magnetic and electronic properties of the high field low temperature large Fermi surface antiferromagnetic state of $CeRhIn_5$.

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