Superconductivity in pyrochlore-type frustrated spin system, $Cd_2Re_2O_7$

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Abstract

^{111}Cd NMR study has been performed in the normal state of superconducting pyrochlore oxide $Cd_2Re_2O_7$. A large orbital susceptibility is identified from K-χ analysis. The sharp decreases of both K and T_1^{-1} below T^* suggests a decrease in density of states which is apparently caused by a developing partial energy gap at the Fermi surface.

Key words:
pyrochlore oxide, spin frustration, superconductor, NMR

1. Introduction

Metallic pyrochlore oxides are very attractive from the aspect of magnetic frustrations since the superconductivity ($T_C \sim 1$ K) have been found in the metallic pyrochlore $Cd_2Re_2O_7$ [1,2]. So far, among the pyrochlore oxide series, $Cd_2Re_2O_7$ is a unique superconductor. In $Cd_2Re_2O_7$ system, the origin of superconductivity may be closely related with the structural transition at $T^* \sim 200$ K which has been known to accompany the decrease of resistivity and susceptibility as shown in Fig. 1.

From X-ray and electron diffraction analysis, it seems reasonable to suppose that the Re tetramerization may occur below T^* [3], which is a similar structural model as Hanawa *et al.* have been discussed [4]. Moreover, another phase transition of 1st order around 100K has been found by Re-NQR measurement [5].

Here, we will give a review of ^{111}Cd NMR results in the normal state of $Cd_2Re_2O_7$.

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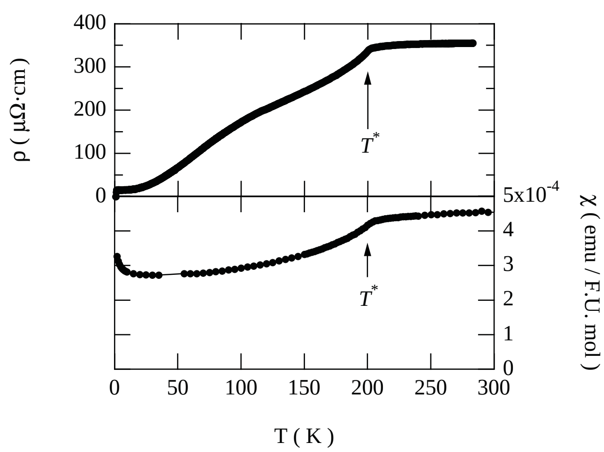

Fig. 1. Temperature dependence of resistivity and susceptibility in $Cd_2Re_2O_7$.

2. Results and Discussion

^{111}Cd NMR measurements for a powder sample were performed using a phase-coherent type pulsed spectrometer. Nuclear spin-lattice relaxation rates T_1^{-1} were measured by an inversion-recovery method

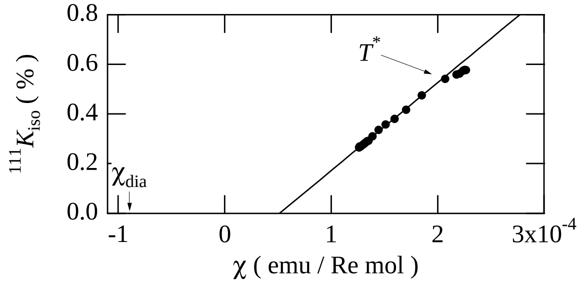

Fig. 2. K-χ plot for ^{111}Cd nuclei in $Cd_2Re_2O_7$.

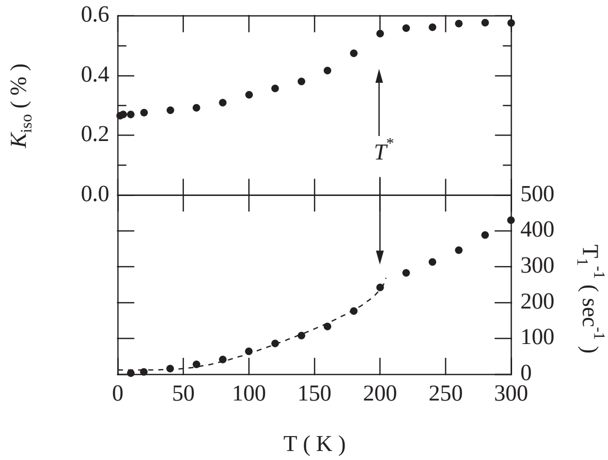

Fig. 3. Temperature dependence of isotropic Knight shift and spin-lattice relaxation rate T_1^{-1} for ^{111}Cd nuclei in $Cd_2Re_2O_7$.

for spin echo signals.

Figure 2 shows a so-called K-χ plot, where values of the isotropic Knight shift $K_{\rm iso}$ are plotted against the observed susceptibility with temperature as an implicit parameter. The hyperfine coupling constant $A_{\rm hf}$ below T^* is estimated to be +198 kOe/$\mu_{\rm B}$. The $A_{\rm hf}$ slightly changes through T^*, which may come from RKKY-type oscillations between Cd nuclei and their neighbouring Re 5d spin polarization. Moreover, the χ-axis intercept of the K-χ plot indicates the presence of a large Re 5d orbital Van Vleck susceptibility.

Figure 3 shows the temperature dependence of isotropic Knight shift and spin-lattice relaxation rate T_1^{-1} for ^{111}Cd nuclei in $Cd_2Re_2O_7$. Above T^* T_1^{-1} increases linearly as expected for Korringa-like relaxation in metallic compounds. Approaching the high temperature, one might expect T_1 to be dominated by exchange-modulated local moment fluctuations on neighboring Re sites, sensed through RKKY-like transferred hyperfine couplings. We estimate $T_1^{-1} = 6T_{1S}^{-1} \sim 3 \times 10^3$ sec^{-1} about an order of magnitude larger than the observed $(T_1T)^{-1}$ at 300 K, where T_{1S}^{-1} is the spin relaxation rate of a single neighbor. This is a reasonable result, which underscores the itinerant nature of the fermion dynamics at 300 K.

The variation of T_1 at low temperature is not in keeping with the behavior of a simple Fermi liquid. About the value of $(T_1T)^{-1}$ at low temperatures, Vyaselev *et al.* have reported that there is a ferromagnetic fluctuation in this system on the basis of a Stoner enhancement model. In the case of T_1 driven by n equal transferred HF couplings with uncorrelated fluctuations, Korringa product $(T_1TK_{\rm spin}^2)^{-1}$ would be diminished by a factor n. Since $n \sim 6$ here, and intermediate cases are entirely possible, this offers a simpler and perhaps more intuitive mechanism to explain the experimental value of $(T_1T)^{-1}$ at low temperatures.

The Korringa product declines just below T^*, and remains approximately constant at 20-30 % of its non-interacting electron value below T^*. These effects appear to be definite evidence that a significant portion of the Fermi surface becomes gapped below T^*. This behavior exhibits a close parallel to that of an underdoped high-$T_{\rm C}$ cuprates. More detailed discussions will be reported elsewhere. [3]

So far, the crystal structure of the low temperature phase has not been determined yet. From ^{111}Cd NMR experiments, the structural phase transition at T^* and the pseudogap state below T^* seem to be essential for occurring a superconductivity at $\sim$ 1 K in this system.

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