Temperature dependent hyperfine interactions in CePdAl

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Abstract

Nuclear Magnetic Resonance have been performed to study hyperfine interactions in CePdAl. The temperature dependence of Knight shift(K) and susceptibility(χ) is highly anisotropic as expected from its crystal structure. Non-linearity of $K-\chi$ plot was observed only when the magnetic field was perpendicular to c-axis. Two dimensional short range correlations are discussed.

Key words: CePdAl; Nuclear Magnetic Resonance; frustration; heavy fermion

1. Introduction

CePdAl is known as an antiferromagnetic heavy fermion compound [1,2]. The temperature dependence of its resistivity shows the typical Kondo behavior. The linear term of specific heat (γ) is 270 mJ mole^{-1} K^{-2} below Néel temperature($T_{\rm N}$ = 2.7 K). Its crystal structure is hexagonal ZrNiAl-type [3]. The most characteristic feature of this crystal structure is the layer structure of Ce atoms in c-plane. Ce atoms have triangular network in c-plane and form Kagome-like lattice. The distance between the nearest neighbor Ce atoms in c-plane is quite small (3.722 Å). Therefore strong magnetic correlations in c-plane and frustration effects are expected. Actually, the nuclear magnetic relaxation rate (T_1^{-1}) showed that the short range correlations start to develop from far above $T_{\rm N}$ [4]. This short range correlation is also remarkable in the large tail of specific heat above $T_{\rm N}$. On the other hand magnetic structure is strongly affected by frustration effects. 1/3 of Ce atoms are still paramagnetic below $T_{\rm N}$ [5].

The strong magnetic anisotropy is observed by susceptibility measurements, which is also ascribed to two dimensional crystal structure. The easy axis is c-axis. The susceptibility (χ) along c-axis shows almost Curie-Weiss behavior with molecular field 5.8 mole/emu [2]. While χ along a-axis shows Curie-Weiss behavior above 30 K with molecular field 97 mole/emu although a significant deviation from Curie-Weiss law appears below 30 K. A large molecular field along a-axis is consistent with the short range correlations in c-plane. In this paper, we report hyperfine interactions above $T_{\rm N}$ studied by nuclear magnetic resonance (NMR). The powder samples of CePdAl fixed in 8 T of magnetic field by Polyethylene Glycol. Therefore the powder is aligned to c-axis. Knight shift(K) and χ of CePdAl along c-axis and perpendicular to c-axis were measured using the fixed powder. K and χ perpendicular to c-axis means the average of those along various directions in c-plane because the powder is aligned only to c-axis.

2. Results and Discussions

Figure 1 shows $K-\chi$ plot of CePdAl. K and χ were measured with magnetic field parallel to c-axis. $K-\chi$ plot is linear in all temperature range. The obtained

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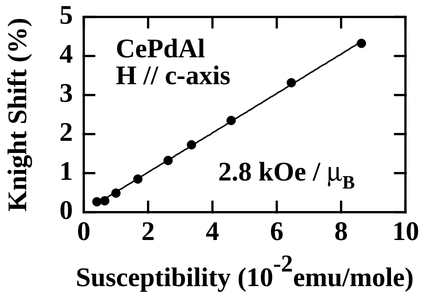

Fig. 1. $K-\chi$ plot of CePdAl between 4.2 K and 205 K. Magnetic field was along c-axis [4](slightly modified).

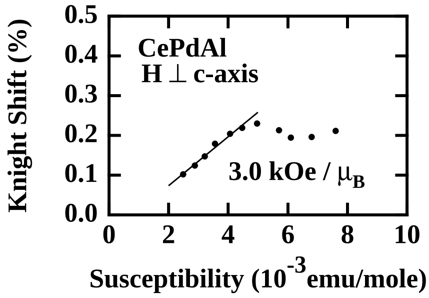

Fig. 2. $K-\chi$ plot of CePdAl between 4.2K and 150K. Magnetic field was perpendicular to c-axis.

hyperfine field is 2.8 kOe/μ_B.

Figure 2 shows $K-\chi$ plot, where K and χ were measured with magnetic field perpendicular to c-axis. $K-\chi$ plot is linear below 20K. The obtained hyperfine field is 3.0 kOe/μ_B. On the other hand a significant non-linearity is observed below 20 K.

At first, we discuss the anisotropy of hyperfine fields above 20 K, where both $K-\chi$ plots are linear. We have to note that there are three kinds of Ce sites when magnetic field is applied perpendicular to c-axis. The direction of principal axis in c-plane of three Ce sites are different from each other although c-axis is always one of principal axes. Furthermore χ is anisotropic even in c-plane. Therefore Ce moments are not parallel to applied magnetic field. The χ tensor is estimated from the crystal field parameters of Stevens' operator equivalents, which are obtained by the fitting of the temperature dependence of χ. The details will be published elsewhere. We took all these complexities into account and estimated the dipolar field at Al sites as the summation of $200 \times 200 \times 200$ unit cells. The directions of magnetic moments are strongly dependent on the direction of magnetic field. The dipolar field at Al sites is distributed from 15 Oe to -15 Oe at 4.2 K. Consequently the dipolar field at Al sites only give the width of spin echo spectra when magnetic field is perpendicular to c-axis. The measured Knight shift does not include the contribution of dipolar fields because K is estimated from the position of the central peak of spin echo spectra. While dipolar field at Al sites is -160 Oe/μ_B when the magnetic field is along c-axis. Minus means that the direction of dipolar field is opposite to the direction of the transferred hyperfine field. This explains the difference between hyperfine field along c-axis and that perpendicular to c-axis. Therefore we can conclude that the anisotropy of hyperfine field is originated from dipolar field and the transferred hyperfine field is almost isotropic above 20 K.

Next we turn to hyperfine fields below 20 K. The remarkable feature is the non-linearity of $K-\chi$ plot with magnetic field perpendicular to c-axis. This means that the transferred hyperfine field becomes anisotropic below 20 K. The non-linearity of $K-\chi$ plot is reported in some compounds and is ascribed to crystal field splittings [6]. However this is not the case. The crystal field splitting between the ground state and the first excited state of CePdAl is much larger than 20 K. The non-linearity of $K-\chi$ plot is also reported in some heavy fermion compounds [7]. However the direction of deviation from the linear relation is opposite in this case. Therefore the origin of the non-linearity is not clear so far. One thing we have to note that the temperature region where $K-\chi$ plot starts to deviate from its linear relation is around the region where the short range magnetic correlation starts to develop as can be seen from specific heat and NMR relaxation rate. From the crystal structure, the development of two dimensional magnetic correlations is expected. This correlation seems to be related with the anisotropy of the transferred hyperfine interactions although the mechanism is unknown for the moment.

In conclusion, the anisotropy of the transferred hyperfine interactions were observed below 20 K. The development of two dimensional magnetic correlations seems to be related with it. Further investigations of the dynamics of magnetic moments are required.

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