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Journal of Magnetism and Magnetic Materials 0 (2006) 1–0

Journal of magnetism and magnetic materials

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NMR study of novel heavy fermion superconductor $CePt_3Si$

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Abstract

^{29}Si NMR experiments were performed to study microscopically the normal and superconducting states in ^{29}Si enriched $CePt_3Si$. A ^{29}Si Knight shift parallel to the c-axis did not decrease below the T_c. The $1/T_1$ result taken with a field cycling method showed no distinct coherence peak just below T_c and a steep decrease below T_c on cooling. The estimated value of the superconducting energy gap was about $2\Delta=3.6k_BT_c$. These results may be an evidence for triplet pairing superconductivity.

PACS: 71.27.+a; 74.20.Mn; 76.60.-k; 76.60.Jx

Keywords: $CePt_3Si$; NMR; superconductivity; relaxation time

1. Introduction

$CePt_3Si$ is a novel heavy fermion superconductor whose T_N and T_c are 2.2 K and 0.75 K, respectively.[1] A lack of an inversion symmetry along the c-axis and a huge critical magnetic field are opposing properties for a mechanism of the superconductivity, which attracts many researchers' interests. To investigate the electronic state in this compound microscopically, ^{29}Si NMR experiments in a ^{29}Si enriched sample were performed.

2. Experimentals

A polycrystalline ^{29}Si enriched $CePt_3Si$ sample was made by a conventional arc melting from Ce (3N), Pt(3N5), ^{29}Si(3N8, 99.8% enriched)+Si(6N, natural) of stoichiometric amounts. Successively, the ingot was annealed at 950°C for one week. A conventional pulsed spectrometer and a superconducting magnet were employed for NMR measurements.

3. Results and Discussion

The T_c was determined by measuring an inductance of the NMR sample coil at a frequency of 1 MHz. The inductance-value decreased monotonically under zero external magnetic field below 0.7 K. Then the $T_c(0)$ was estimated as 0.7 K. Under magnetic field of 1 T, the $T_c(H)$ decreased to 0.6 K, which is almost the same value compared with that in the previous report.[1]

Fig. 1 shows the NMR spectra of ^{29}Si in $CePt_3Si$ at 4.2 K and 1.1 K. Below T_N, the line width becomes broader and broader with decreasing temperature due to an internal magnetic field from ordered Ce moments. As the sample powder was free in the sample case, the c-axis of the sample powder oriented easily to the external magnetic field due to an anisotropy of the susceptibility. The internal magnetic field (H_{int}) in the antiferromagnetic state can be estimated as about 230 Oe from the width of the spectrum at 1.1 K. Assuming a dipole magnetic interaction to be a main mechanism for the internal field, the magnetic moment at the Ce site can be estimated as about 0.5 μ_B, which is

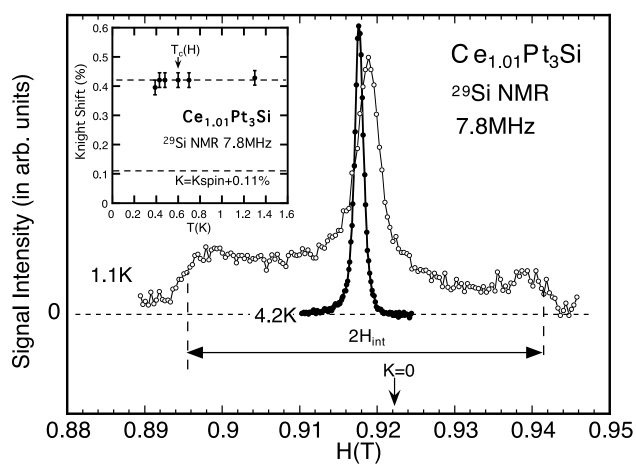

Fig. 1. Line shapes of ^{29}Si NMR at 4.2 K and 1.1 K are plotted by closed circles and open circles, respectively. The inset shows temperature dependence of the Knight shift of the central peak, which is corresponding to the oriented sample powder whose c-axis is parallel to the external magnetic field.

about three times larger than that obtained by the neutron diffraction experiment.[2]

The inset of Fig. 1 shows a temperature dependence of a Knight shift determined from a central peak of the spectrum around T_c. In generally, the Knight shift (K) is expressed as $K = K_{spin}(T) + K_0$, where $K_{spin}(T)$ and K_0 are arising from a temperature dependent spin susceptibility and a temperature independent term, respectively. In a case of a conventional BCS superconductor, the K approaches to the K_0 (0.11%) as the temperature decreases. The K_0 is determined experimentally as a value of an intercept on a K-axis, which corresponding to the extrapolation of the K-χ line to high temperature in a K-χ plot.[3] However, no distinct decrease was observed, as can be seen in the inset. This result may become one of the evidence of a triplet pairing. Frigeri *et al.* reported that $K_{\perp c}$ component is a key data to conclude what type of pairing in the superconducting $CePt_3Si$ is realized.[4] So, systematic measurements of $K_{\perp c}$ vs. the external field and the temperature are now in progress.

Since our used sample with high quality (small concentration of impurities and/or imperfections of lattice) has long coherence length near the T_c, the influence of the vortex core can not be ignored. Moreover, it become difficult for a conventional comb pulse method to saturate the nuclear magnetization for a broad spectrum due to the antiferromagnetic internal field without heating up the sample. To solve these difficulties, a field cycling method, which makes the T_1 measurements for ^{29}Si under very low external magnetic field possible, was employed. Of course, an adiabatic condition of the field switching, $dH_0/dT \gg H_0/T_1$, where H_0 is a resonance magnetic field, was satisfied.

The enriched sample has two time-components of T_1: One has long T_1 value, which is a characteristic of the superconductivity, and the other has a shorter relaxation time. At this stage, it is not clear whether the short time component of T_1 is of an intrinsic property or not.

Fig. 2 shows the temperature dependence of a $1/T_1$ at the Si site below 4.2 K. Open circles and open squares are the results taken by the conventional comb pulse method with short and long time components, respectively. Closed circles and closed squares are the results by the field cycling method with short and long time components, respectively. The data of the long time-component obtained by the field cycling methods were in good agreement with the data taken by the comb pulse method. However, the data of the short time-component taken by the field cycling method gave shorter relaxation times than the data of the short time-component taken by the comb pulse method. This may be ascribed to insufficiency of the adiabatic condition. Then, we focus our discussions on long time-components especially on one which is obtained by the field cycling method.

Below T_N, on the other hand, T_1 become longer due to an appearance of a gap in the conduction electron state by the antiferromagnetic ordering. Far below the T_N, the T_1 shows Fermi liquid behavior followed by a "$1/T_1 \propto T$" relation.

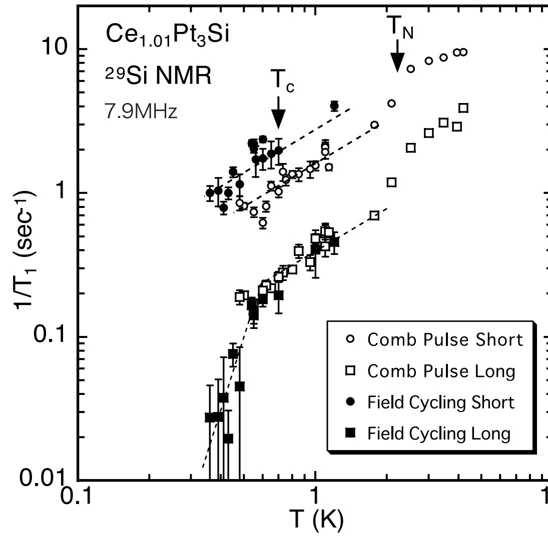

Fig. 2. Temperature dependences of $1/T_1$'s of ^{29}Si nuclei below 4.2 K. Open circles and open squares are the results taken by a conventional comb pulse method with short and long time components, respectively. Closed circles and closed squares are the results by a field cycling method with short and long time components, respectively. Dotted lines are guides for eyes.

Below the T_c, the long component of field cycling measurement showed no obvious Hebel-Slichter peak and shows a drastic decreasing ($1/T_1 \propto T^3 \sim T^5$). A similar behavior was previously reported on Pt sites.[5] Assuming an isotropic superconducting energy gap, the value of the gap can be estimated as about $2\Delta = 3.6 \pm 0.7 k_B T_c$. This result is favorable for the model of a triplet pairing.

4. Conclusion

Below the T_c, no distinct decrease of the Knight shift of the c-axis parallel to the external field was observed in a ^{29}Si enriched sample. Just below the T_c, no obvious Hebel-Slichter peak in $1/T_1$ was observed within an experimental error. The superconducting energy gap is estimated to be about $3.6 k_B T_c$. These NMR results suggest that spin triplet pairing is probably realized for the superconductivity.

This work was partially supported by a Grant-in-Aid from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

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