Neutron Diffraction Study of $5f$ Itinerant Antiferromagnet $UPtGa_5$ and $UNiGa_5$

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Abstract

Magneto-striction and magnetic form factors in $5f$ itinerant antiferromagnet $UNiGa_5$ and $UPtGa_5$ are studied by means of neutron scattering. Remarkable magneto-striction was observed around T_N, indicating large spin-orbit coupling in the itinerant system. The orbital magnetic moment is found to be strongly suppressed due to the hybridization of uranium $5f$ with Ga-$4p$ electron.

Key words: $UTGa_5$, magnetic form factor, magneto-striction, itinerant antiferromagnetism

The f electron systems attract much interest because of the unconventional superconductivity and the coexistence with the magnetic ordering around the quantum critical point. Recent studies reported a new series of heavy fermion superconductor $CeTIn_5$ (T:Rh, Co, Ir)[1–3], which is followed by the discovery of high-T_C heavy fermion superconductor $PuCoGa_5$[4]. On the other hand, the iso-structural compounds $UT'Ga_5$ exhibit strong itinerant character of $5f$ electrons, $UT'Ga_5$ with T′=Fe, Co, Ru, Rh, Os, Ir exhibit Pauli paramagnetic behavior, while $UNiGa_5$, $UPdGa_5$, and $UPtGa_5$ are itinerant $5f$ antiferromagnet which show the characteristic weak magnetic susceptibility and a small ordered moment.[5] Our recent neutron scattering study revealed the magnetic structures in $UNiGa_5$ and $UPtGa_5$. The difference in the magnetic structure of these iso-electronic compounds were discussed in terms of the orbital ordering. In the present study we report the existence of magneto-striction and suppression of the orbital magnetic moment in $UNiGa_5$ and $UPtGa_5$ to shed light on the nature of the itinerant antiferromagnetism with uranium $5f$ electrons.

The neutron powder diffraction data were measured on HRPD at the research reactor JRR-3 in Japan Atomic Energy Research Institute. The magnetic form factors were measured by the triple-axis spectrometers TAS-1 and TAS-2. The details of sample preparation were published elsewhere.[6,8]

The lattice constants a and c are platted as a function of temperature in Figs. 1 and 2 for $UNiGa_5$ and $UPtGa_5$, respectively. The lattice constants were obtained by Rietveld analysis using RIETAN-2000[9]. Small reliable factors typically R_{wp}=5.48, R_e=4.82, R_F=1.59 and S=1.16 for $UPtGa_5$ indicate the correctness of our analysis with the accuracy of lattice constants in the order of 10^{-4} Å. $UNiGa_5$ showed lattice expansion/contraction in the antiferromagnetic state (T_N=86 K) along the a- and c- axis, respectively. In contrast, the lattice expands both in the a and c directions below T_N=26 K in $UPtGa_5$. The existence of the remarkable magneto-striction is indicative of

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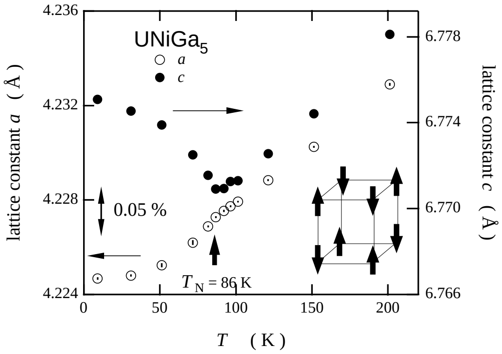

Fig. 1. Temperature dependence of lattice constants, a(open circle) and c(closed circle) in $UNiGa_5$. The arrow indicates the transition temperature of T_N=86 K.

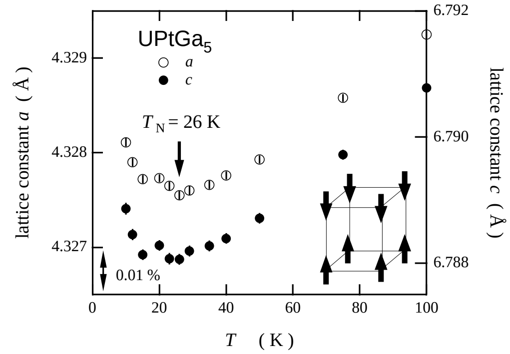

Fig. 2. Temperature dependence of lattice constants, a (○) and c (●) in $UPtGa_5$. The arrow indicates T_N=26 K.

the large spin-orbit coupling. The opposite sign of the magneto-striction in the direction can be reasonably understood from the magnetic structure as shown in the inset of Figs. 1 and 2. The in-plane nearest-neighbor coupling is antiferromagnetic in $UNiGa_5$, while that coupling is ferromagnetic in $UPtGa_5$.

Figure 3 shows the magnetic from factor observed in $UNiGa_5$. $\mu f(\boldsymbol{Q})$ can be described by the sum of Bessel's function within the dipole approximation,

$$\mu f(\boldsymbol{Q}) = \mu(\langle j_0\rangle + C_2\langle j_2\rangle + \cdots) \qquad (1)$$

where μ is the total magnetic moment and $\boldsymbol{Q}$ is the momentum transfer. The observed form factor clearly deviates form the one for U^{3+} free ion shown as dotted line. The fitted result using Eq. 1 is shown by the solid lines with μ=0.87(4) μ_B and C_2 =2.57(21) . It means that the contribution of the orbital moment μ_L/μ_S = -1.64 is suppressed from the value for free ion of μ_L/μ_S = -2.56. This suppression is most probably due to the hybridization of $5f$ electrons with Ga-$4p$ electrons. Nevertheless, it is noteworthy that a large orbital moment exists in the itinerant antiferromagnet based on uranium $5f$ electrons, which is consistent with the existence of magneto-strictions. A smaller suppression of μ_L/μ_S = -2.1 was also observed in $UPtGa_5$.

The suppression of the orbital moment was reported in an itinerant $5f$ antiferromagnet UGa_3 as well. The orbital contribution μ_L/μ_S=-1.66 is very close to that obtained for $UNiGa_5$. Note that $UNiGa_5$ and UGa_3 show a very flat magnetic susceptibility for T>T_N, while a weak Currie-Weiss behavior with a small effective moment μ_{eff}=1.8 μ_B was observed in $UPtGa_5$. It roughly means that the strength of the hybridization in $UNiGa_5$ might be comparable with UGa_3 but stronger than that in $UPtGa_5$. Therefore, we conclude that the quenching of the orbital moment is correlated with the itinerancy of $5f$ electrons.

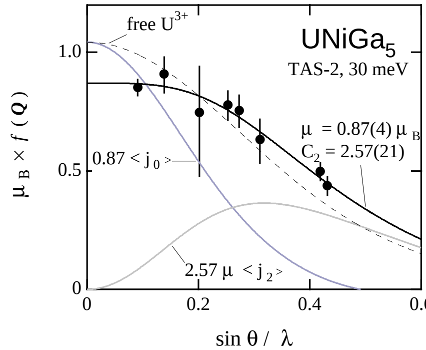

Fig. 3. Magnetic form factor of $UNiGa_5$ at 4 K.

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