Magnetic instability induced by Rh doping in the Kondo semiconductor $CeRu_2Al_{10}$

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The ternary compound CeT_2Al_{10} (T = Fe, Ru, and Os) is a unique system that shows Kondo semiconducting behavior at low temperatures, and it exhibits an antiferromagnetically (AFM) ordered state at $T_0 \sim 30$ K for T = Ru and Os, while a nonmagnetic ground state is observed for T = Fe, as is usually the case for Kondo semiconductors (or insulators).[1-3] Since the magnetic susceptibility (χ) systematically decreases on changing the transition metal element in the order from T = Ru to Os to Fe, the $4f$ electron state is located in the vicinity of the boundary between localized and non-localized states, as expected from the Kondo semiconducting behavior. Thus, the c-f hybridization between d- and $4f$-electrons must play a key role for their low-temperature properties involved in the origin of the AFM order.

The AFM order is very unusual. T_0 is quite high for a usual Ce-based intermetallic compound when taking into account, for instance, the long distance of 5.2 Å between neighboring Ce ions.[2] The magnetic anisotropy is also unusual. Although the easy axis is the a axis with the large magnetic anisotropy ($a \gg c \gg b$), the AFM ordered moment (m_{AF}) with a magnitude of 0.3−0.4 μ_B/Ce aligns in the c-axis direction.[4,6] Recently, the Rh-doping effect on $CeRu_2Al_{10}$ has been examined, where Rh ($4d^8$) has one electron more than Ru ($4d^7$).[7,8] On the basis of the results, we infer that χ becomes more Curie−Weiss like and decreases drastically below T_0 for $H \| a$. These results imply that the Rh-doping breaks $m_{AF} \| c$ and $m_{AF} \| a$ is realized instead. In order to clarify the spin alignment and the critical Rh concentration x_c from a microscopic point of view, we performed zero-field μSR on $Ce(Ru_{1-x}Rh_x)_2Al_{10}$ (x = 0, 0.03, 0.05, and 0.1).

Figure 1 shows the temperature dependence of the internal magnetic field (H_{small}, H_{large}) at the muon site for $Ce(Ru_{1-x}Rh_x)_2Al_{10}$. Here, H_{small} (H_{large}) represents the smaller (larger) component of internal magnetic fields. For the undoped sample, H_{small} shows non-mean-field-like behavior, while H_{large} increases below T_0 and saturates to a value of about 180 G below about 15 K. On the other hand, for Rh-doped samples, H_{large} reaches about 800 G at low temperatures. This strongly suggests the spin-flop transition from $m_{AF} \| c$ to $m_{AF} \| a$ on the basis of our dipolar field calculation at the suggested muon site, which is consistent with the bulk properties.[7,8] Since there is no Rh-concentration dependence in H_{large} for $x > 0.03$, the boundary of the different magnetic ground states is identified at around $x \sim 0.03$. The drastic change of the magnetic ground state by such a tiny Rh doping indicates that the magnetic structure in $CeRu_2Al_{10}$ is not robust and can be quite easily tuned using external perturbations such as d-electron doping. On the basis of previous experimental results from thermal electric power,[9] neutron scattering,[4] and NQR measurements,[10] the non-mean-field-like behavior of H_{small} for the $x = 0$ sample is attributed to the Fermi contact field from the polarized electrons at the muon site, while the T dependence of H_{large} for the Rh-doped samples is still an unresolved question; whether it results from the Fermi contact field or from the unusual ordering of Ce^{3+} moments should be clarified by future neutron scattering experiments.

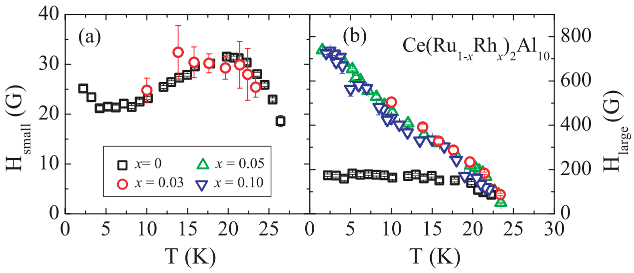

Fig. 1. Temperature dependence of the internal magnetic fields at the muon sites in $Ce(Ru_{1-x}Rh_x)_2Al_{10}$ (x = 0, 0.03, 0.05, and 0.1): (a) H_{small} (b) H_{large}.

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