NMR Study of the Spin Fluctuation in $Ce(Ru_{1-x}Rh_x)_2Si_2$

K. Ueda[1], S. Mishina[1], T. Kohara[1], Y. Yamamoto[2], Y. Miyako[2]
[1]Faculty of Science, Himeji Institute of Technology, Kamigori, Hyogo 678-1297, Japan.
[2]Graduate School of Science, Osaka Univ., Toyonaka 560, Japan.

Spin-lattice relaxation times (T_1) were measured on x=0.03 and x=0.05 samples of $Ce(Ru_{1-x}Rh_x)_2Si_2$ in a temperature range between 1.5 K and 60 K. Temperature dependences of T_1 in both samples do not obey the Korringa relation, and are well described by the SCR theory for an antiferromagnetic ground state. Four parameters of y_0, y_1, T_0, T_A obtained by the best fitting have close values obtained by specific heat experiments. The positive y_0 value in x=0.05 means that the sample of x=0.05 has no magnetic ordering at finite temperature, which contradicts with the experimental results of neutron diffraction, specific heat and susceptibility.

Introduction: $CeRu_2Si_2$ with $ThCr_2Si_2$ type crystal structure is a typical non-magnetic dense Kondo compound with $\gamma_0 = 360$mJ/molK^2 [1]. The magnetic ground state is characterized as a Fermi liquid with antiferromagnetic correlations. The substitution of Ru by Rh was found to induce easily an antiferromagnetic phase (spin density wave: SDW) transition at low temperatures. Recently, the longitudinal incommensurate SDW transition in $Ce(Ru_{1-x}Rh_x)_2Si_2$ ($0.03 < x < 0.4$) has been found to undergo by nesting of 4*f*- of Ce and 4*d*-hole of Ru bands [2]. The recent neutron scattering experiment has shown that there exists an antiferromagnetic short range ordering with the correlation length of about 6 nm along the *c*-axis at x=0.03, while no long range magnetic ordering appears down to 0.1 K in macroscopic measurements of the specific heat and the susceptibility measurements.

On the other hand, the self-consistent renormalization (SCR) theory has established to describe the spin fluctuation effect of itinerant electrons in 3*d*-transition metal compounds [3]. Ishigaki et al. have tried to apply the same model to the heavy Fermion state [4]. The heavy Fermion state is usually formed near the (antiferro)magnetic instability due to the competition of the Kondo effect and the RKKY interactions. Since the amplitude of spin fluctuation are enhanced near the magnetic instability and strongly dependent of temperature (T) near the critical concentration (x_C). Here we focus on the paramagnetic state near x_C=0.03 and the SDW state formed at 2 K in the Fermi liquid state of x=0.05, and report the results of ^{29}Si NMR and ^{101}Ru NQR and the discussion based on the SCR theory in this paper.

Experimental Results and Discussions: The single crystal used here is the same as those used for specific heat, susceptibility and μSR measurements. Fig.s 1 (a), (b) and (c) are anisotropic powder patterns of ^{29}Si NMR spectra with an axial symmetry observed in the sample (x=0.03) oriented randomly and in the sample (x=0.05) aligned along external field at 4.2 K and 1.5 K, respectively. The powder samples were easily oriented to the *c*-axes in the external field because of the highly anisotropic susceptibilities.

In $Ce(Ru_{0.95}Rh_{0.05})_2Si_2$ with T_N of 2.0 K the relaxation rates at some field-points in the characteristic lineshape associated with the SDW formation are not different so much each other down to 1.5 K. So we may measure the spin-lattice relaxation rate ($1/T_1$) at the peak position on the spectrum (Fig. 1 (b),(c)) of each aligned sample through T_N.

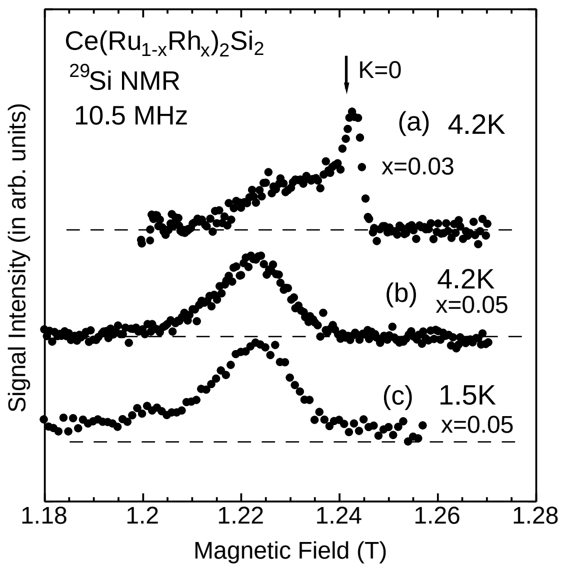

Fig. 1. ^{29}Si NMR spectrum of $Ce(Ru_{1-x}Rh_x)_2Si_2$. (a) A random oriented powder pattern of Si NMR in x=0.03 sample. (b) and (c) are oriented powder pattern for x=0.05 sample whose *c*-axis is parallel to the magnetic field at 4.2 K and 1.5 K, respectively.

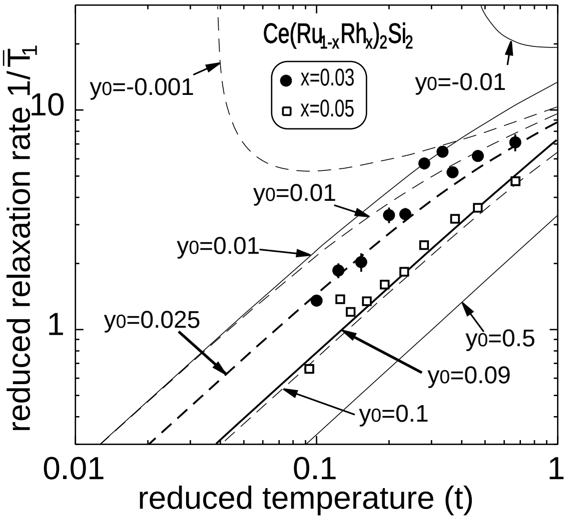

Fig. 2. A plot of reduced relaxation rate ($1/\bar{T}_1$) vs. reduced temperature ($t = T/T_0$). Dashed lines and solid lines are calculated relaxation rates for various y_0 values in x=0.03 and x=0.05 sample, respectively. See text. ● and □ are the measured values for x=0.03 and x=0.05, respectively.

Shown in Fig. 2 are the reduced relaxation rates ($1/\bar{T}_1$) in both samples against the reduced temperature ($t = T/T_0$), where each reduced quantity is proportional to the measured one. Both relaxation rates are not proportional to T, but approximately to $T^{1/2}$ in high T range. The characteristic $T^{1/2}$ dependence of $1/T_1$ indicates that the SCR theory by Moriya et al. is applicable to describe the relaxation behaviors of these compounds with antiferromagnetic correlations [3]. According to the SCR theory for an antiferromagnetic ground state on the relaxation rate $1/T_1$ is expressed by

$$1/T_1 = \frac{3\hbar\gamma_{\rm n}^2 A_{\rm hf}^2}{8k_{\rm B}T_{\rm A}}\frac{t}{\sqrt{y}},$$

$$y = y_0 + \frac{3}{2}y_1\int_0^{x_{\rm c}} x^2[\ln u + \frac{1}{2u} + \psi(u)]dx,$$

where $\psi(u)$ is the digamma function, $x_{\rm c}$ is the reduced cut-off wave vector and $u = (y + x^2)/t$ [4]. Here y_0, y_1, T_0 and $T_{\rm A}$ are a parameter for a measure of distance from magnetic instability, a strength of the magnetic exchange interaction, a characteristic temperature of spin fluctuations in the ω-space, and a characteristic temperature of spin fluctuations in the q-space, respectively.

As seen in Fig. 2, the SCR theory explains well the measured relaxation rates by using four parameters, y_0, y_1, T_0, $T_{\rm A}$, which are 0.025, 0.3, 15 K, and 12 K in x=0.03 and 0.09, 0.1, 15 K and 6 K in x=0.05, respectively. Indeed, these parameters except for y_0 in x=0.05 are in good agreement with those obtained by recent specific heat measurement [5]. The positive y_0 value in x=0.05 means that the sample of x=0.05 has no magnetic ordering at finite temperature, which contradicts with the experimental results of neutron diffraction, specific heat and susceptibility. Besides, as mentioned above, $1/T_1$ was taken on the aligned sample with magnetic easy axis parallel to the magnetic field. To compare the experimental results under the external field with the SCR theory in the heavy electron compounds with a strong anisotropy, the improved SCR theory by taking account of an anisotropy is highly desired.

Finally, ^{101}Ru NQR signals were also observed in both samples at around 10 MHz. The relaxation measurements in Ru NQR, together with the analyses for the characteristic lineshapes of ^{29}Si NMR and ^{101}Ru NQR associated with the occurrence of the SDW in x=0.05, are now in progress.

The authors would like to thank Prof. Y. Takahashi for valuable discussions. This work is partially supported by a Grant-in-Aid from the Ministry of Education, Science and Culture of Japan.

References:

[1] J.D. Thompson et al., Solid State Commun. 56 (1985) 169.

[2] Y. Miyako et al., J. Phys. Soc. Jpn. 65 (1996) Suppl. B 12.

[3] T. Moriya and K. Ueda, Solid State Commun. 15 (1974) 169.

[4] A. Ishigaki and T. Moriya, J. Phys. Soc. Jpn. 65 (1996) 3402.

[5] Y. Tabata et al., J. Phys. Soc. Jpn. 67 (1998) 2284.