CONF-820659--6

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^{11}B STUDY OF SPIN DYNAMICS IN $Y_{1-x}RE_xRh_4B_4$*

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June, 1982

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To be Presented at the IV Conference on Superconductivity in d- and f-band Metals, Kernforschungszentrum Karlsruhe, Germany, June 28-30, 1982

*Work Supported by the U.S. Department of Energy.

MASTER

^{11}B STUDY OF SPIN DYNAMICS IN $Y_{1-x}RE_xRh_4B_4$*

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There has been intense interest in re-entrance and coexistence in ternary rare earth magnetic superconductors of the form RE Rh_4B_4. Of particular interest in this investigation is the effect of the superconducting state on the RKKY (Yosida, 1957) coupling between RE ions. Since one expects the conduction electron spin susceptibility $\chi^e(q)$ to be cut off for $q < 1/\xi$ in the superconducting state, a depression of the RKKY coupling should follow. Such an effect would both depress the magnetic ordering temperature and result in slower relaxation rates τ_m^{-1} for the RE moments in the superconducting state. In this paper we report on the spin dynamics of the RE ions using the ^{11}B nuclear magnetic relaxation rate T_1^{-1} in dilute $Y_{1-x}RE_xRh_4B_4$ (RE = Gd and Er).

For pure YRh_4B_4 and $LuRh_4B_4$, the ^{11}B relaxation time T_1 is displayed in Fig. 1 as a function of reciprocal temperature. The nuclei relax via the contact hyperfine interaction with the conduction electron spins. In the normal state T_1 follows the Korringa behavior (Korringa, 1950) with $T_{1K}T$ = constant. Below $T_c(H)$, the relaxation rate is first enhanced and then decreases as the superconducting gap opens up. The low temperature behavior $T_1^{-1} \sim e^{-\Delta/k_BT}$ agrees with the BCS prediction $2\Delta(0) = 3.52\ k_BT_c$. The enhanced relaxation rate at low (300 G) applied field has been discussed in terms of the strength of the nuclear electric quadrupole interaction at ^{11}B (Fradin, et al, 1981).

The local moment induced ^{11}B relaxation in $Y_{1-x}Gd_xRh_4B_4$ and $Y_{1-x}Er_xRh_4B_4$ for x = 0.0002, 0.002, 0.005 is found to follow a square root dependence on time, indicating lack of spin diffusion (McHenry, et al, 1972) between boron nuclei, i.e., the ^{11}B nuclei relax independently to the lattice. The longitudinal nuclear magnetization recovery is given by

$$\frac{M_z(\infty) - M_z(t)}{M_z(\infty)} = e^{-t/T_1} e^{-(t/\tau_1)^{1/2}} \quad (1)$$

The largest contribution to the local moment induced nuclear relaxation τ_1^{-1} comes from the anisotropic terms of the dipolar coupling between the rare earth moment and the nuclear moment in which the z-component of the electronic moment is conserved (Giovannini, et al, 1971). The so-called longitudinal dipolar relaxation rate is given by

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Work supported by the U.S. Department of Energy.

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$$\frac{1}{\tau_1}\Bigg)_{LD} = \frac{16\pi^3}{9}(\gamma_m\gamma_n\hbar\, Jx)^2 \frac{\delta B_J(\chi)}{\delta\chi}\frac{\tau_{m_1}}{1+(\omega_n\tau_{m_1})^2} \qquad (2)$$

where γ_m and γ_n are the rare moment and nuclear moment gyromagnetic ratios, respectively, g_J is the Lande g-factor, J is the RE total angular momentum, B_J is the Brillouin function, τ_{m_1} is the longitudinal relaxation time of the rare earth moment, and ω_n is the nuclear Larmor frequency. In Fig. 2, we display $\tau_o)_{LD}$ as a function of reciprocal temperature for $x = 0.002$ Er, where $\frac{1}{\tau_1}\Big)_{LD} = \frac{\delta B_J(\chi)}{\delta\chi}\frac{1}{\tau_o}\Big)_{LD}$. The magnitude, field dependence, and the minimum in $\tau_o)_{LD}$ is clear evidence for the longitudinal dipolar mechanism, if we recognize that $\omega_n = \gamma_n H$ and assume a temperature dependent τ_{m_1}.

In Fig. 3 we display $\tau_{m_1}^{-1}$ as a function of 1/T from the data in Fig. 2 and Eq. (2), using the full $J = 15/2$ Brillouin function. (Crystal field effects will be discussed in an extended paper.) Similar results are found for dilute Gd. In the normal state $\tau_{m_1}^{-1}$ is independent of temperature and applied field and proportional to the local moment concentration as expected for the RKKY interaction:

$$\frac{1}{\tau_{m_1}}\Bigg)_{RKKY} = \frac{2}{3}\pi^2\left[\frac{1}{6}\,\pi(g-1)^2 J(J+1)\right]^{1/2} N(0)^2 \mathcal{J}^2 x\,\frac{E_F}{\hbar k_F^3} \qquad (3)$$

where N(0) is the density of states at the Fermi level, $\mathcal{J}$ is the local moment conduction electron effective exchange interaction, and E_F and k_F are the Fermi energy and momentum, respectively. The competing Korringa relaxation of the local moment via the exchange interaction with the conduction electron spins is given by

$$\frac{1}{\tau_{m_1}}\Bigg)_{K} = \frac{\pi}{\hbar}(N(0)\mathcal{J})^2 k_B T \qquad (4)$$

We find the Korringa mechanism is not important in the normal state at 10 K and would be expected to become much less effective in the superconducting state as the gap opens. We infer that $N(0)\mathcal{J} \leq 3 \times 10^{-3}$. The fact that the RKKY interaction appears to be effective at such dilution is worthy of further consideration. (The direct dipolar coupling between local moments is an order of magnitude smaller.) Interestingly from a comparison of τ_{m_1} in the normal state, we find from Eq. (3) that $N(0)\mathcal{J}$ is approximately equal for both Gd and Er doped compounds.

Of most importance is the dramatic drop of $\tau_{m_1}^{-1}\Big)_{RKKY}$ in the superconducting state. Although there is a clear field dependence of $\tau_{m_1}^{-1}\Big)_{RKKY}$ there appears to be a smooth transition through H_{c_1} ($\simeq$600 gauss). We would expect a reduction of the RKKY interaction in the superconducting state since the effective $\vec{S}\cdot\vec{S}$ coupling strength

$$\Gamma(r_{ij}) = \mathcal{J}^2 \frac{\mathrm{Re}\chi^e(r,\omega)}{(g\mu_B)^2}$$ depends on the conduction electron spin susceptibility. Matsui and Masuda (1977) have shown that in the limit of $x \to 0$, the real part of the conduction electron susceptibility $\chi^e(r,\omega)$ is reduced as tanh $\left(\frac{\Delta(T)}{2T}\right)$.

The detailed analysis of the local moment relaxation time in the superconducting state will be presented in an extended paper. However, the sharp reduction of the RKKY coupling below T_c should be an important factor in any assessment of the role of superconductivity in suppressing the magnetic transition.

The authors would like to thank J. W. Downey for experimental assistance.

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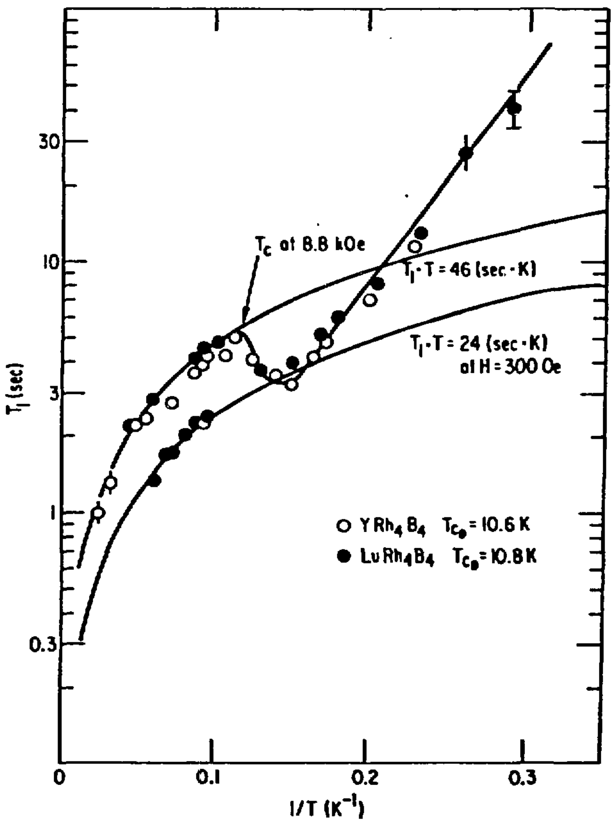

Fig. 1. *^{11}B nuclear spin-lattice relaxation time versus reciprocal temperature for YRh_4B_4 and $LuRh_4B_4$. The high field (8.8kOe) and low field (300 Oe) Korringa curves are shown as is the high field transition into the superconducting state.*

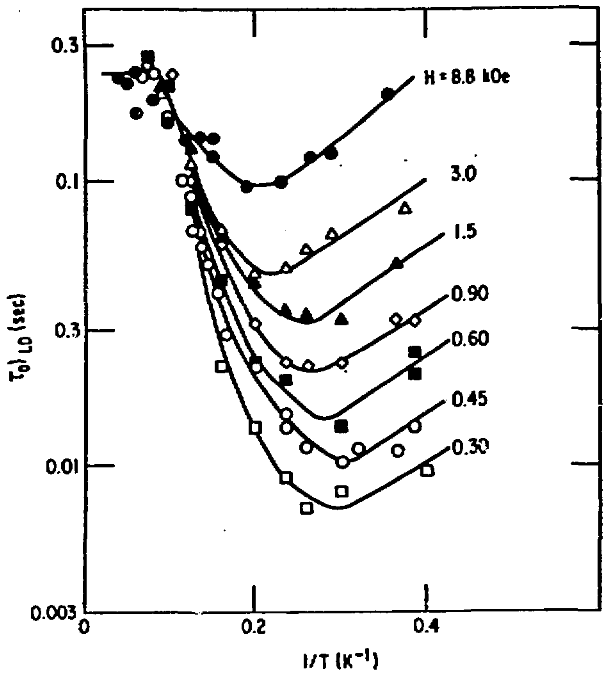

Fig. 2. ^{11}B nuclear spin-lattice relaxation time versus reciprocal temperature for $Y_{0.9998}Er_{0.0002}Rh_4B_4$ as a function of applied magnetic field. $\tau_0 = \tau_1 \; \delta B_J(\chi)/\delta\chi$ with $J = 15/2$.

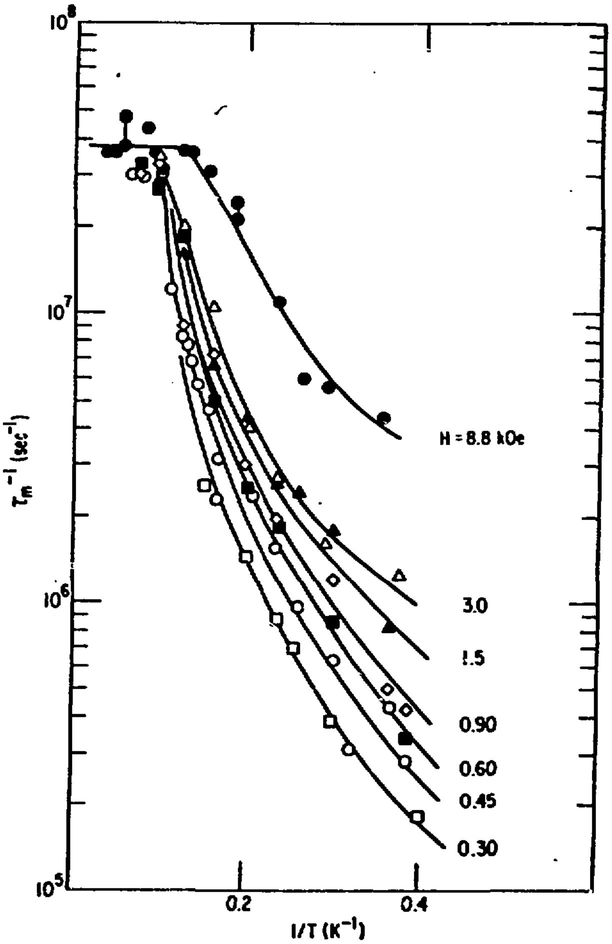

Fig. 3. Longitudinal relaxation rate for Er in $Y_{0.9998}Er_{0.0002}Rh_4B_4$ versus reciprocal temperature as a function of applied magnetic field.