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LOW-FIELD ^{11}B NMR IN YRh_4B_4 *

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An Adiabatic field cycling technique is used to study the ^{11}B nmr in the anomalous ternary superconductor YRh_4B_4 at fields below H_{c1} .

Nuclear magnetic resonance and magnetization measurements⁽¹⁾ on the ternary superconductor $\text{Y}_{1-x}\text{Er}_x\text{Rh}_4\text{B}_4$ with $0 \leq x \leq 0.1$ indicate a surprisingly large conduction electron spin polarization with negligible depression of T_c . It was also reported that there was a rapid loss of the observable ^{11}B nmr signal for $1.0 < T_c/T \lesssim 1.25$ due to inhomogeneous magnetic broadening, which is not expected for this strongly type-II superconductor.

Because of the long ^{11}B spin-lattice relaxation time T_1 in the undoped YRh_4B_4 ($T_1 \approx 5$ sec @ 11°K) and the large ^{11}B nmr signals in the normal state, we have used an adiabatic demagnetization/remagnetization cycle to study the relaxation behavior in fields $H < H_{c1}$. The advantages of the field cycle are that we measure changes in the large normal state signal for $H > H_{c2}$ due to relaxation processes in low fields $< H_{c1}$ in the superconducting state. We, thus, combine high field sensitivity with the ability to study low field interactions. The procedure is for the nuclear spin system to come to thermal equilibrium at high fields $\sim 6\text{kG}$ at (8MHz resonance frequency) in a superconducting solenoid. The solenoid is then cycled to a low field in a few milliseconds. For a T_1 measurement in low field the time at low field is then the independent parameter to be varied. The field is then cycled back to the original high field in about 70 msec and the ^{11}B spin echo signal $M(\tau)$ is measured with a $\frac{\pi}{2} - \pi$ pulse sequence. We find that $M(\tau) \sim \exp(-\tau/T_1)$. In a series of companion experiments we measure the internal field distribution using a train of pulses to heat the spin system while in the low field state; in this experiment τ is fixed ($\tau \ll T_1$) and the radio frequency ν of the spin heating pulses is the independent parameter. We again use a spin-echo pulse sequence to measure changes in the high field signal $M(\nu)$.

Because of the nuclear electric quadrupole interaction $e^2qQ/h = 700(30)\text{kHz}$, a unique spin temperature, and thus the adiabatic conditions could not be maintained for field cycles down to zero field. That is, as the Zeeman splitting of the $I=3/2$ manifold becomes small compared to the quadrupole splitting, the energy levels become unevenly split and the $\Delta M = \pm 1$

spin flips become difficult. Thus, the time to establish a common spin temperature becomes prohibitively long at fields below $\sim 200\text{G}$.

At a field of 200G, the absorption of energy from the rf pulse train is essentially unchanged between the normal ($T > 10.6\text{K}$) and superconducting ($T < 10.6\text{K}$) states. The absorption is characteristic of a mixed quadrupolar and Zeeman interaction⁽²⁾ with a random angle between the axis of the electric field gradient and the magnetic field, which is expected for a powder. The maximum absorption of energy is near 330kHz and the absorption extends from below 200kHz to 650kHz. We thus have little sensitivity to detect changes in the internal field distribution between the normal and superconducting state. Clearly, single crystals would be of great advantage for determining internal field changes in a mixed quadrupolar and Zeeman system.

The ^{11}B nuclear spin-lattice relaxation time was measured at a field of 200G for $0.92 \leq T_c/T \leq 1.22$, see Fig. 1. In the normal state, the Korringa relaxation time, $T_1T \approx 14$ sec $^\circ\text{K}$, is 25% of the high field value.

If we use the expression⁽³⁾

$$T_1(H) = \frac{H^2 + H_D^2 + H_Q^2}{H^2 + 2H_D^2 + 3H_Q^2} T_1(\infty)$$

and ignore the dipolar field H_D compared to the effective quadrupolar field H_Q that is in spin temperature equilibrium, we find $H_Q = 350\text{G}$. For $1.0 \leq T_c/T \leq 1.07$, the Korringa relaxation rate $R \equiv 1/T_1$ increases over the normal state value reaching a ratio $R_S/R_N = 1.7$ at $T_c/T = 1.07$. For $T_c/T \geq 1.07$, the relaxation rate in the superconducting state $R_S \sim \exp(-\Delta/k_B T)$ with $2\Delta = 6.6k_B T_c$. This can be compared to the BCS value of $2\Delta(0) = 3.5k_B T_c$.

If we try to explain the gap based on strong coupling corrections, we can use the expression⁽⁴⁾

$$2\Delta(0) = 3.52k_B T_c \left[1 + 5.3(T_c^2/\omega_0^2) \ln(\omega_0/T_c) \right]$$

The solution of this equation for $2\Delta(0) = 6.6 k_B T_c$ yields a characteristic phonon frequency $\omega_0 = 21K$, clearly an unphysical result.

The source of the large gap $\Delta = 3meV$ can perhaps be found in the same mechanism that yields the large inhomogeneous magnetic broadening found in the high field results(1) for $1.0 < T_c/T \lesssim 1.25$. An exponential relaxation has also been found(5) for ^{27}Al in the complex antiferromagnet $CeAl_2$ and has been described as due to relaxation controlled by excitation across a magnon gap. Such an effect, though clearly not associated with 4f electrons, may also be operative in YRh_4B_4 .

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Figure 1: ^{11}B spin-lattice relaxation time at 200G in YRh_4B_4 ; dashed curve is the normal state Korringa relaxation time.