J. Phys. Soc. Jpn. **52** (1983) Suppl. p. 199–201

STUDY OF MAGNETIC SOLITON BY NUCLEAR MAGNETIC RELAXATION

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Experimental evidences for Sine-Gordon soliton and propagative domain-boundary have been obtained from the nuclear spin-lattice relaxation studies for easy-plane ferromagnet $CsNiF_3$ and Ising-like canted antiferromagnet $CsCoCl_3 \cdot 2H_2O$, respectively.

Non-linear excitation (soliton) in one-dimensional magnet has recently been one of the most interesting topics in solid state physics. The present work is concerned with the nuclear spin-lattice relaxations associated with soliton dynamics in two types of one-dimensional systems; easy-plane ferromagnet $CsNiF_3$ and Ising-like antiferromagnet $CsCoCl_3 \cdot 2H_2O$. The experiments were carried out using a coherent pulsed-NMR technique in the temperature range between 1.5 K and 20 K.

$CsNiF_3$ (T_N=2.7 K) is known as the best system for the study of Sine-Gordon 2π-soliton. The relaxation time T_1 of ^{133}Cs measured with an external field H_o (1.5 kOe∼12 kOe) applied in the easy-plane exhibited remarkable field and temperature dependences, which suggested the existence of two important relaxation mechanisms. Magnon contribution was first evaluated by making exact numerical calculations for the two-magnon and the three-magnon processes within the framework of conventional linear spin-wave theory. The experimental data fit well to the prediction of the three-magnon process (the second-order exchange-enhanced process) quantitatively as well as qualitatively for relatively high fields and low temperatures. Next, analysis was attempted on a soliton model such that the nuclear relaxation is due to collisions with one-dimensional dilute soliton gases, which led to a qualitative expression;

$$T_1^{-1} \sim T^{-1}\exp(-c\sqrt{H}/T), \qquad (1)$$

where H is magnetic field in the

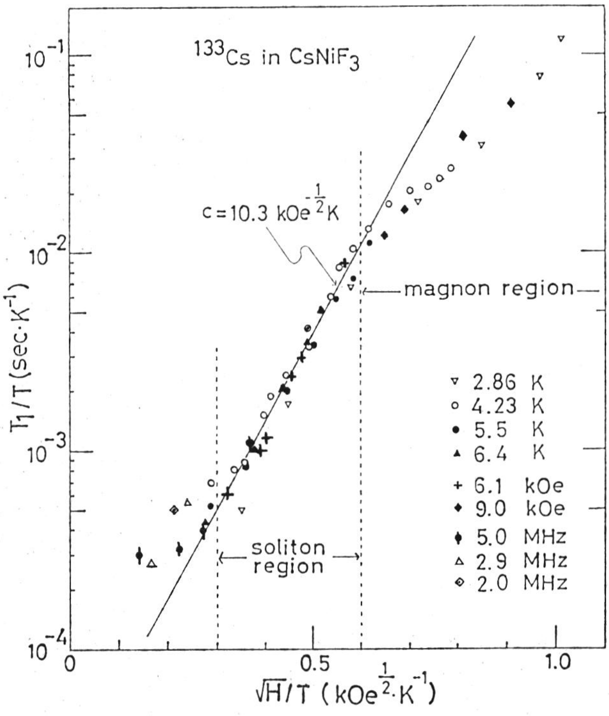

Fig.1. Experimental values of T_1/T vs. $\sqrt{H}/T$ for ^{133}Cs in $CsNiF_3$. Solid line represents the best-fit curve based on the soliton model, which is obtained by taking c= 10.3 $(kOe)^{-1/2}$K in the eq.(1) in the text.

easy-plane. Taking c to be 10.3 $(\mathrm{kOe})^{-1/2}\mathrm{K}$ resulted in a satisfactory fit of the eq.(1) to the experimental data which deviated from the prediction of the three-magnon process. The situation is clearly demonstrated in Fig.1, which shows the selected experimental values of T_1/T vs. $\sqrt{H}/T$, where $H=H_o-H_d$, H_d being the demagnetization field. The soliton model is found to be valid for the field and temperature regions like $0.3 \lesssim \sqrt{H}/T \lesssim 0.6$ $(\mathrm{kOe})^{1/2}\mathrm{K}^{-1}$. Magnon-dominated regions are the ones like $0.6 \lesssim \sqrt{H}/T$. Our value of c yields soliton activation energy smaller by about 30 % as compared with the theoretical value, which is consistent with the result for the neutron inelastic scattering experiment.[1] A preliminary account of this work has been reported previously,[2] and details have been presented at ICM '82.[3]

Spin dynamics of Ising-like antiferromagnet is characterized by propagative domain-boundary. Canted antiferromagnet $CsCoCl_3 \cdot 2H_2O$ [4] (T_N=3.3 K in zero field) is an appropriate system to study this problem. Previously, we have reported on ^{133}Cs spin-lattice relaxation in this compound.[5] Experimental features are as follows. (See Figs.2 and 3.) For the external field H_o applied parallel to the c-axis (nearly Ising-axis), the relaxation rate T_1^{-1} increases remarkably but rather monotonously as the temperature decreases near to T_N. For H_o//a-axis (chain direction with a small weak moment), on the other hand, there appears a maximum of T_1^{-1} around a certain temperature which is not related to the three-dimensional ordering. In fact, the shift of resonance field associated with the long-range ordering was never observed below this

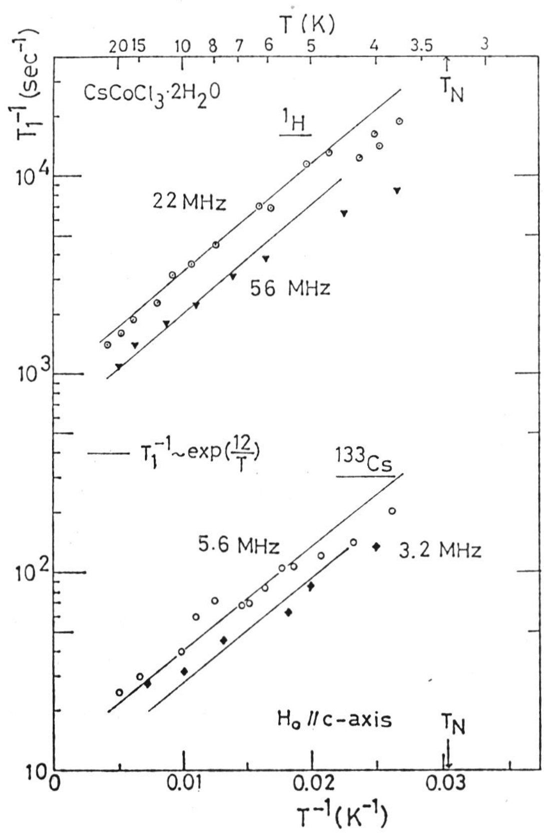

Fig.2. Temperature dependences of T_1^{-1} of ^{133}Cs and ^{1}H in $CsCoCl_3 \cdot 2H_2O$ for H_o //c-axis. Solid lines represent the best-fit curves based on the soliton model, the eq.(2) in the text.

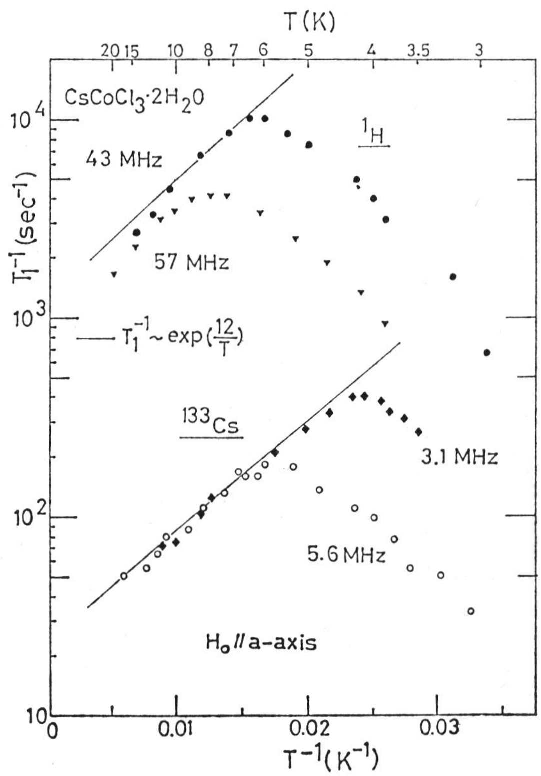

Fig.3. Temperature dependences of T_1^{-1} of ^{133}Cs and ^{1}H in $CsCoCl_3 \cdot 2H_2O$ for H_o//a-axis. Solid lines represent the best-fit curves based on the soliton model, the eq.(2) in the text.

temperature. It is also noted that the external field applied along the a-axis causes a phase transition to a paramagnetic phase with critical field of 2.9kOe at T=0 K. [4] The value of T_1 and the temperature corresponding to the maximum have a trend to increase with increasing temperature. On the higher temperature side, the temperature dependence of T_1 is almost the same as that for H_o//c-axis. The relaxation mechanism was assumed to be due to the longitudinal correlation of the antiferromagnetic q=π mode which diminishes with a damping constant $\Gamma_q = \langle v \rangle / \xi$, where ξ is correlation length of Ising chain (= $(1/2)\exp(|J|/kT)$),and $\langle v \rangle$ is the mean velocity of boundaries ($=\varepsilon|J|/\hbar$, ε being the exchange anisotropy). Then, under the condition that ω_N (nuclear Lamour frequency) $\ll \Gamma_q$, we obtained

$$T_1^{-1} \sim \Gamma_q^{-1} \sim \exp(|J|/kT) \qquad (2)$$

By taking J/k to be 12 K, the eq.(2) fit well to the data for H_o//c-axis, as shown by the solid line in Fig.2. As for the case H_o//a-axis, the temperature dependence of T_1^{-1} on the higher temperature side was found to be interpreted in the same way, as shown by the solid line in Fig.3. This equation, however, does not explain the appearance of $(T_1^{-1})_{max}$.

Quite recently, the appearance of such a $(T_1^{-1})_{max}$ has been observed in impure antiferromagnetic chain $(CD_3)_4NMn_{(1-c)}Cu_cCl_3$ [6] and Ising-like antiferromagnet $CsFeCl_3 \cdot 2H_2O$ [7]. The experimental features have been interpreted in terms of an equation;

$$T_1^{-1} \simeq \Gamma/(\omega_N^2 + \Gamma^2), \qquad (3)$$

where Γ is the flipping rate of the antiferromagnetic domains. Then, the appearance of $(T_1^{-1})_{max}$ has been ascribed to the realization of the condition $\omega_N=\Gamma$, although the expression for Γ is different depending on "coherent" (non-interacting soliton) model or "incoherent" (diffusive) model. The damping constant used in the eq.(2) is essentially the same as Γ for coherent model, and in fact, the $(T_1^{-1})_{max}$ in $CsCoCl_3 \cdot 2H_2O$ seems to be interpreted by the eq. (3). To confirm this point, we have measured T_1 of ^1H in this compound. The experimental results are shown in Figs.2 and 3. As is seen, the bahaviour of T_1 of ^1H is quite similar to that of ^{133}Cs. It should be noted, in particular, that the temperature at which $(T_1^{-1})_{max}$ appears does not depend on the nuclear Lamour frequency but only on the strength of the applied field. (Compare the curves for ^{133}Cs (ν_N=5.58 MHz/10 kOe) at 5.6 MHz and ^1H (ν_N=42.3 MHz /10 kOe) at 57 MHz.) Thus, in the case of $CsCoCl_3 \cdot 2H_2O$, the criterion for $(T_1^{-1})_{max}$ seems to be due to the strength of the applied field along the a-axis or the electron Lamour frequency. It may be necessary to consider the transverse correlation. Then, the presence of a weak moment along the a-axis and the resulting change in correlation length caused by the external field along the a-axis may play some role. The answer has not yet been found out.

In conclusion, it has been shown that the nuclear spin-lattice relaxations in $CsNiF_3$ and $CsCoCl_3 \cdot 2H_2O$ provided experimnetal evidences for the solitons in respective cases.

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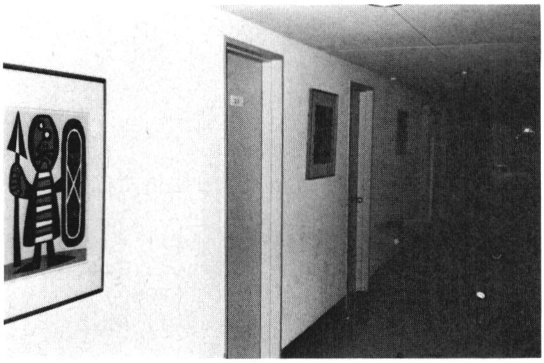
INSIDE VIEW OF KANSAI SEMINAR HOUSE (3)

Robby in the main building.



Corridor in the main building.