UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL ATOMIC ENERGY AGENCY
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

SMR.998a - 13

Research Workshop on Condensed Matter Physics
30 June - 22 August 1997
MINIWORKSHOP ON
QUANTUM MONTE CARLO SIMULATIONS OF LIQUIDS AND SOLIDS
30 JUNE - 11 JULY 1997
and
CONFERENCE ON
QUANTUM SOLIDS AND POLARIZED SYSTEMS
3 - 5 JULY 1997

"Nuclear spin relaxation and instability of spin motion in the low field phase of nuclear-ordered solid 3He"

T. MIZUSAKI
Kyoto University
Department of Physics
Faculty of Science
Kitashirakawa, Yoshid a Hormachi Sakyo
60601 Kyoto
JAPAN

These are preliminary lecture notes, intended only for distribution to participants.

MAIN BUILDING STRADA COSTIERA, 11 TEL. 2240111 TELEFAX 224163 TELEX 460392 ADRIATICO GUEST HOUSE VIA GRIGNANO, 9 TEL.224241 TELEFAX 224531 TELEX 460449
MICROPROCESSOR LAB. VIA BEIRUT, 31 TEL. 2249911 TELEFAX 224600 TELEX 460392 GALILEO GUEST HOUSE VIA BEIRUT, 7 TEL.2240311 TELEFAX 2240310 TELEX 460392

Nuclear Spin Relaxation and Instability of Spin Motion in the Low Field Phase of Nuclear-ordered Solid ^{3}He

Takao Mizusaki
Department of Physics, Kyoto University,
Kyoto 606-01, Japan

Nuclear spin dynamics in the low field phase of nuclear-ordered solid ^{3}He is reviewed. The linear regime of spin dynamics was investigated by cw-NMR. Nuclear spin relaxation mechanisms were studied by measuring the linewidth of cw-NMR and were attributed to three- and four-magnon processes. The small negative frequency shift was observed and is attributed to the thermal fluctuation effect around the mean field equations. Pulsed NMR was used to investigate nuclear spin dynamics in nonlinear regime. The nuclear spin motion became unstable under certain conditions. Under stable conditions the spin motion can be described by the OSF equations. The tipping-angle-dependent frequency shift and multiple spin echoes were observed, which are similar to the case of superfluid ^{3}He. The onset of the instability of spin motion is attributed to the stimulated emission mechanism through the three-magnon relaxation process, which is similar to the Suhl instability in electronic magnetism. We derived the magnon life time from an analysis of the instability. During the instability, a large negative frequency shift was observed. This negative shift is explained by the extension of Fomin-Ohmi's theory to include the state of decayed magnon and this explanation is consistent with the instability model.

1. Nuclear Spin Relaxation Mechanisms (cw-NMR)

The nuclear-ordered solid ^{3}He is a unique system to study the nuclear spin dynamics where the nuclear spin itself is in the collective ordered-state. Nuclear-ordered solid ^{3}He has been extensively studied experimentally and theoretically and its properties are well described by the multiple-exchange interaction and the dipole interaction between nuclear spins. Thus elementary excitation and the thermal properties of the ordered solid can be described by magnons and all nuclear-magnetic properties can be studied by a microscopic base. Two nuclear-ordered phases were found in magnetic fields, U2D2 phase in low fields and the normal canted antiferromagnetic phase in high fields. The NMR on the low field phase is particularly interesting for investigating spin dynamics since this ordered phase has a uniaxial magnetic symmetry and the large coherent dipole torque is operative non-linearly to spin motions. Solid samples in this work are limited throughout to bcc solid ^3He on the melting curve.

The cw-NMR was investigated by Osheroff, Cross and Fisher (OCF)[1] who determined the nuclear-spin structure of the low field phase, called U2D2 phase, from their analysis of the observed cw-NMR spectrum. They proposed the equations of spin motion (OCF Equations) from the symmetry consideration of this antiferromagnet and the mean-field argument.

The antiferromagnetic cw-NMR resonance frequency is well described by OCF Eqs. except for a small negative frequency shift[1, 2, 3]. Recently Fomin and Ohmi[4] included the thermal fluctuation effect in the OCF Eqs. and explained the negative shift. Sasaki et al.[2] studied spin relaxation mechanisms in U2D2 phase by measuring the field-dependence of the line width of cw-NMR and clarified experimentally the nuclear-relaxation mechanisms due to the three-magnon process and four-magnon processes. Their result agreed well with Ohmi and Tsubota's theory[5].

2. Spin Motion in Nonlinear Regime (pulsed NMR)

Spin dynamics in the low field phase are studied by using a pulsed NMR in the nonlinear region where the nuclear spins are tipped away from the equilibrium condition. Kusumoto et al.[6] performed for the first time pulsed NMR on this system and studied spin dynamics. They found an anomalous free induction decay (FID) signal where the decay time depended on the tipping angle. There has been much theoretical work done on the spin dynamics in the U2D2 in the nonlinear regime[7-12].

We discuss spin dynamics in the nonlinear regime in a single crystal sample with a single U2D2 magnetic domain in high fields where the Larmor frequency is much larger than the zero field antiferromagnetic resonance frequency[13]. We found the instability of spin motion under certain conditions. In this section the features of the instability of spin motion are described and the onset condition of the instability as for strength and direction of applied fields, temperatures and tipping angles are clarified.

3. Spin Dynamics in Stable Region in Nonlinear Regime

In the stable region we investigate whether the OCF Eqs. can describe spin motion in the nonlinear regime, comparing the result with Namaizawa's[7] tipping-angle-dependent frequency shift and the multiple spin echo signal. We conclude that spin dynamics in the stable region are well described by the OCF Eqs. except for the effect of the negative frequency shift.

4. Instability of Spin Motion in Nonlinear Regime

Several theories for the instability of the uniform behavior of the FID have been proposed, such as the chaos of the uniform motion in the low fields [8], the instability of the uniform precession against the creation of long-wave-length spin wave [9,10] and the formation of the homogeneous precession domain[11]. But none of them explains the instability we observed. We propose a model for instability of nuclear spin motion due to the self-induced emission mechanism which is similar to the Suhl instability for electronic spin system [14,15] and compare it with the results.

The time evolution of the FID signal after an rf-pulse changed in time in the unstable region and the FID frequencies showed a large negative shift during the rapid decay. Recently Ohmi[16] reformulated their result[4] and calculated the negative frequency shift as a function of the population density of the lower magnon branch. Together with his theory, our instability model could explain this large negative shift observed in the rapid decay. The onset conditions agreed with our model. From an analysis of the onset condition, the magnon lifetime was estimated as a function of temperature and magnetic field (k-dependence). After the instability takes place, our results do not agree quantitatively with the model and further rigorous theoretical treatment of spin dynamics in nonlinear regime is necessary.

References

[1] D. Osheroff, M.C. Cross and D.S. Fisher, Phys. Rev. Lett. **44** (1980) 792.
[2] Y. Sasaki et al., Phys. Rev. **B44** (1991) 7362.
[3] Y.P. Feng, P. Schiffer and D.D. Osheroff, Phys. Rev. Lett. **67** (1991) 691.
[4] I.A. Fomin and T. Ohmi, Phys. Lett. **A180** (1993) 141.
[6] T. Ohmi and M. Tsubota, J. Low Temp. Phys. **83** (1991) 177.
[6] T. Kusumoto et al., *ibid.* **59** (1985) 269.
[7] H. Namaizawa, Prog. Theor. Phys. **67** (1982) 1989.
[8] M. Tsubota, Prog. Theor. Phys. 79 (1988) 47.
[9] T. Ohmi, M. Tsubota and T. Tsuneto, *ibid.* **73** (1985) 1075.
[10] D.V. Shopova, Phys. Lett. **A156** (1991) 455.
[11] I.A. Fomin and D.V. Shopova, JETP Lett. **42** (1985) 199.
[12] M. Tsubota, T. Ohmi and T. Tsuneto, Prog. Theor. Phys. **76** (1986) 1222.
[13] T. Matsushita et al., J. Low Temp. Phys. **89** (1992) 365; Physica **B194-196** (1994) 929; Low Temp. Phys. **22** (1996) 137; J. Low Temp. Phys. **105** (1996) 67.
[14] See, M. Sparks, *Ferromagnetic-Relaxation Theory* (McGraw-Hill Book Company, London, 1964), ch. 8.
[15] H. Suhl, J. Phys. Chem. Solids, **1** (1957) 209
[16] T. Ohmi, private communications.