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MAGNETIC RELAXATION OF ^{3}He-B AFTER A LARGE TIPPING PULSE

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A time dependent precession frequency is observed in ^{3}He-B after a large tipping pulse (>104°) in transverse NMR. Relating the frequency to the tipping angle reveals the time dependence of the longitudinal magnetization. A fit of Fomin's theory to the data yields the Leggett–Takagi collision time at various temperatures.

Spin relaxation phenomena in superfluid ^{3}He have gained considerable interest recently [1]. Though some of the observed phenomena [2–6] can be understood quite well in terms of the known equations of motion describing the dynamical behavior of the magnetization, several important aspects of spin relaxation remain to be investigated. For example, as far as we know a detailed understanding of intrinsic spin–orbit relaxation effects in the superfluid states has not yet evolved. In our present work we have studied longitudinal spin relaxation of bulk ^{3}He-B by means of pulsed transverse NMR at tipping angles well above 104°. Our data can be described by a relaxation law which was derived by Fomin [7] as an approximate analytical solution of the Leggett–Takagi equations of motion. From our data we then can determine the Leggett–Takagi collision time τ_{LT} which sets the time scale for the magnetizations of the condensate and the quasi-particles to come into equilibrium [8]. Our results compare very well with calculations of τ_{LT} by Einzel [9].

At a pressure of 18.7 bar the ^{3}He sample was cooled below the superfluid transition temperature T_c by means of adiabatic demagnetization of 0.25 mole of $PrNi_5$. Temperature was measured by means of a platinum NMR-thermometer which was calibrated at T_c and at temperatures in the vicinity of 50 mK. T_c was detected by the steep drop of the spin–lattice relaxation time of ^{3}He below the transition temperature. The ^{3}He NMR coil was located near the platinum coil and operated at Larmor frequencies ν_0 of 529 kHz and 874 kHz. In the superfluid spin relaxation was studied with tipping pulses which typically were in the range between 130° and 140°. The free induction decay was recorded with a transient recorder. In fig. 1 a photograph of a signal (actually taken from a storage scope) is shown. A beat pattern is observed which we found to be caused by a superposition of a signal at Larmor frequency, mainly coming from regions near the edges of the ^{3}He coil, and a frequency shifted signal from the center of the coil. Similar signals were observed earlier by other authors [3]. However, it is also evident from fig. 1 that the frequency shift decreases with time. This has not been observed earlier [‡1].

In the B phase at tipping angles $\beta > \theta_0 = \arccos(-\frac{1}{4}) \approx 104°$ the frequency shift $\Delta\nu$ is given by the Brinkman–Smith relation

$$\Delta\nu/\nu_0 = -\tfrac{16}{15}(\nu_B/\nu_0)^2(1 + 4\cos\beta)\,, \qquad (1)$$

where ν_B is the characteristic frequency of the B phase at a given temperature and pressure. Hence, from the time dependence of the shift (as determined from the zero crossings of the beat pattern) the relaxation of the

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[‡1] Recently observations similar to ours were reported in ref. [10].

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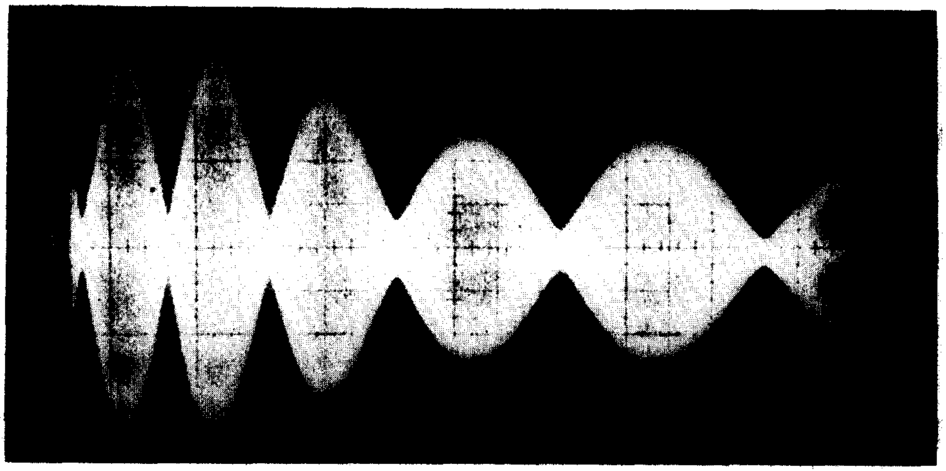

Fig. 1. Free induction signal after a 128° tipping pulse. Time scale is 1 ms.

tipping angle β can be inferred as long as $\beta > \theta_0$. A particular relaxation law which applies to our experimental situation has recently been derived by Fomin [7]. It is calculated from the Leggett–Takagi equations and is valid in the hydrodynamic limit ($\Omega_B \tau_{LT} \ll 1$) for strong and homogeneous magnetic fields ($\nu_0^2 \gg \nu_B^2$):

$$dP/dt = -\kappa (16\nu_B^2/15\nu_0^2)^2 P(P+2)(P+\tfrac{5}{4})^2 , \qquad (2)$$

where $P = \cos\beta - 1$, and the parameter κ is related to the form of energy dissipation as discussed by Leggett and Takagi [8], i.e.

$$\kappa = \omega_0^2 \tau_{LT} [(1-\lambda)/\lambda] (\chi/\chi_0)$$

(notation of ref. [8] is used). Eq. (2) can easily be integrated and in combination with eq. (1) be fitted to our data. Fitting parameters are κ and the initial tipping angles $\beta(0)$. As can be seen from fig. 2 our data are consistent with eq. (2).

It should be mentioned that the analysis is very sensitive to $\nu_B(T/T_c)$ since $d\Delta\nu/dt \propto \nu_B^6$ for given β. We took the Helsinki ν_B data at 18.7 bar as tabulated in ref. [1] (above $T = 0.9T_c$ an extrapolation was used). It also turns out that the relative change of the frequency shift scales as ν_0^{-2} thereby favoring small Larmor frequencies for observing the relaxation. We also noticed that the decay constants of the free induction signal prevented us from obtaining reliable data over a larger time interval. The region close to 104° could not be investigated in this work. It is, however, expected that eq. (2) which predicts relaxation to approach θ_0 asymptotically, will not be valid there since relaxation is known to proceed below θ_0 by a mechanism which is not included in the Leggett–Takagi equations.

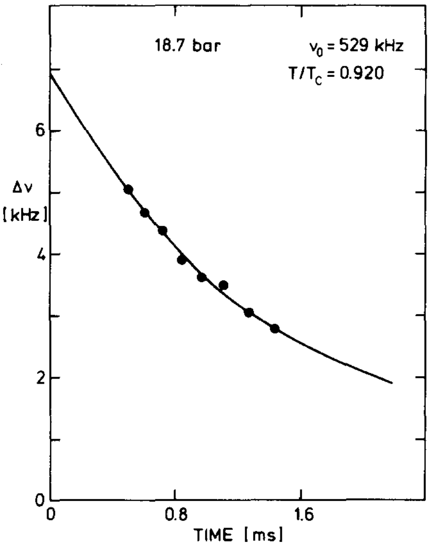

Fig. 2. Time dependence of the frequency shift after a 146° pulse. The solid line is a fit to Fomin's law, see eq. (2).

In fig. 3 our results for κ/ω_0^2 are shown as a function of reduced temperature. Calculations by Einzel [9] and Wölfle [11] compare well with our data. Some discrepancy exists above $T/T_c = 0.9$ the reason of

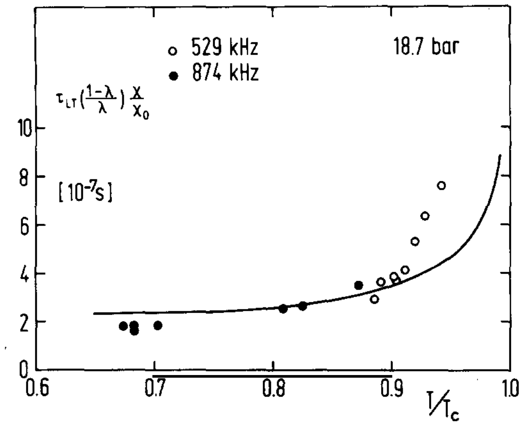

Fig. 3. Temperature dependence of the spin relaxation time. The solid line is from a calculation by Einzel (ref. [9]).

which remains uncertain. Since errors in ν_B (or T/T_c) have a remarkable influence in particular near T_c we have tried to leave ν_B as a fit parameter in eq. (2). This would have changed the data points above $0.9T_c$ somewhat but would not have removed the discrepancy with the theoretical curve. On the other hand experiments on the relaxation of the wall-pinned mode [1] above $0.9T_c$ agree quite well with this theory [9,11]. Therefore, this problem remains open to further investigation.

In summary, we may say that our experimental results and the existing theories [7,9] by and large give a consistent picture of the longitudinal spin relaxation at large tipping angles in bulk superfluid ^{3}He-B.

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