SQUID NMR Studies of the Dipole Field in Ferromagnetic ^{3}He films

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Abstract

We use SQUID NMR to observe the magnetization of ^{3}He films with densities between 20 to 24 atoms/nm^2 in the zero field limit. Ferromagnetism in these nearly 2D Heisenberg exchange systems is stabilized by weak anisotropies. In the ferromagnetic phase, the NMR line becomes very broad and shifts to lower frequencies, consistent with a large dipolar field opposing a perpendicular applied field. Grafoil can be modeled by a Gaussian distribution of platelet angles centered on the normal to the Grafoil plus a randomly distributed set of platelets. Using the spin dynamics of a 2D polarized sheet with reasonable assumptions for the distributions of platelet angles, we show that the magnetization, frequency shift and lineshape form a consistent picture of a highly polarized sheet.

Key words: NMR; Grafoil; ^{3}He; SQUID

Recent studies of ^{3}He films at USC in the zero field limit have shown that there is a rapid onset of magnetization in the vicinity of 1 mK temperatures, implying the existence of finite order.[6] This increase in magnetization is observed from both the rapid increase in the magnitude of the NMR absorption signal and a shift in the NMR frequency along with a characteristic change in lineshape due to a dipole field from the aligned ^{3}He spins. The NMR signal increases by more than four orders of magnitude across our measurement range.

In Fig. 1, we show four typical NMR absorption lines at different temperatures. The data we show here is for a ^{3}He film at areal density of 22.5 atoms/nm^2 and 0.35 mT applied field. The nominal direction of the applied field is perpendicular to the Grafoil planes. We see that along with a frequency shift, there is a rapid broadening of the NMR lines as the temperature is lowered and there is a distinctly asymmetric shape. The general features of the frequency shift and lineshape changes can be attributed to the increasing nuclear dipolar field of the polarized ^{3}He spins. In this paper we show that this shape is due in part to the distribution of platelet angles in the Grafoil and the spin dynamics of the ^{3}He in the presence of a small applied field. The Grafoil platelet angle distribution has been well studied using neutron scattering[1–3] and x-ray scattering[4]. The platelet angular distribution is shown to be from two parts, a Gaussian part centered around the normal of the Grafoil and a random distribution part:

$$P(\theta_h) = [a * exp[-(\frac{\theta_h}{\pi/6})^2] + b] * sin(\theta_h) \qquad (1)$$

where a and b are two dependent normalized prefactors for the Gaussian and random portions. The random fraction has been reported to be in the range from 50%[1,2] to 33%[4].

The spin dynamics of a two-dimensional sheet in an arbitrary magnetic field has been described in Friedman *et al.*[5]. When an external field is applied, for each platelet angle θ_h, there is a corresponding local angle for the magnetization due to the competition between the applied field and the local dipolar field. The local processional frequency ω_0 then depends on the orientation of the magnetization, the platelet angle θ_h, the applied field H_0 and the dipolar field λM_0. One important assumption is then made: the frequency distribution is not a δ-function at processional frequency ω_0, but a broader distribution. We find that Gaussian function

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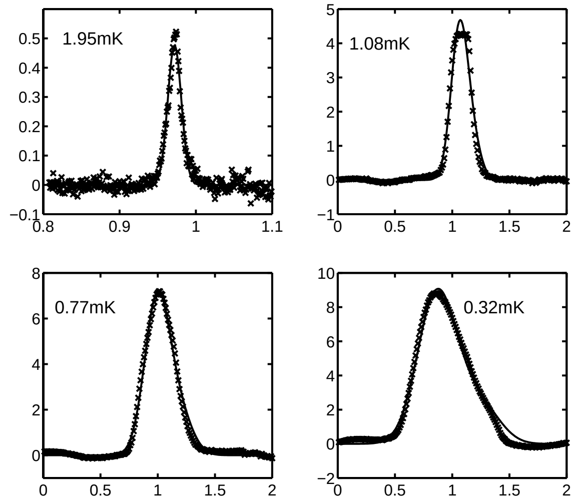

Fig. 1. CW absorption signals at four temperatures (crosses) with the fitted line shape. 25% random platelet. X axis is frequency and in unit of 10KHz, Y axis is amplitude in unit of 10^{-3}. Note the different vertical scales for the NMR signals.

centered at ω_0 fits the data better than a Lorentzian:

$$f(\omega) = c * exp[-(\frac{\omega - \omega_0}{width})^2] \quad (2)$$

where c is a prefactor and *width* is the intrinsic linewidth. Finally, the total frequency distribution from all the platelets is:

$$F(\omega) = \Sigma_{\theta_h} P(\theta_h) * f(\omega) \quad (3)$$

This model is used to fit our NMR absorption lines with three fitting parameters: c, *width* and λM_0. The values of a and b held constant throughout the fitting process. However, we have used a number of different values for a and b corresponding to different assumptions about the fraction of the signal coming from the random fraction. The fitted NMR lines are shown in Fig.1 as solid lines. We can see, the fitting procedure works better at the higher and lower temperatures with some still unexplained shape in the intermediate range close to 1 mK.

From the fitting process, we found the fraction of randomly distributed platelets should be set closer to 25% rather than 40-50%. In Fig.2, we show the best achievable fitting result of 40% random platelet fraction at 0.32 mK, and it clearly overestimates the magnitude of the high frequency side of the NMR line (coming from the statistical preponderance of plates oriented close to $\theta_h = \pi/2$).

The results for linewidth and dipolar field from fitting to this model were reported in Bozler *et al.* [6]. They show that the dipolar field along with the magnetization are consistent with a large polarization (order unity) as the temperature approaches zero – even in the zero field limit. Although the underlying linewidth derived from our fit is considerable less than the apparent width of the lines in Fig. 1, it nevertheless increases rapidly so that its width is similar to the dipole field. One component of this width that we have not taken into account is the distribution of the dipolar field across finite planes (typically 100 Angstroms). We estimate this effect to be about 10% of the linewidth.

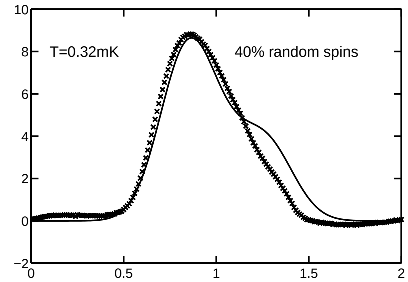

Fig. 2. CW absorption line fitting at T=0.32 mK with 40% random portion. Axis settings are same as Fig.1.

We do not find it especially surprising that a significant fraction of the randomly aligned surfaces do not contribute to our low temperature signal. This is most likely due to some of those surfaces being either very small and perhaps not crystalline, and thus do not contribute to the ferromagnetic signal. In all of these experiments, paramagnetic components of the signal are completely negligible as compared with the huge enhancements of the ferromagnetic signal.

Acknowledgements

This research is supported by the National Science Foundation grant DMR-9973255.

References

[1] H. Godfrin and H.J. Lauter, *Progress in Low Temperature Physics*, **XIV** edited by W.P.Halperin (Elsevier, Amsterdam, 1995) p. 213.

[2] H.P. Schildberg and H.J. Lauter, *Surf. Sci.* **208** (1989) 507.

[3] J.K. Kjents, L. Passell, H. Taub, J.G. Dash and A.D. Novaco, *Phs. Rev. B* **13** (1976) 1446.

[4] C. Bouldin and E.A. Stern, *Phs. Rev. B* **25** (1982) 3462.

[5] L.J. Friedman, S.N. Ytterboe, H.M. Bozler, A.L. Thomson, and M.C. Cross, *Phys. Rev. Lett.* **57** (1986) 2943; L.J. Friedman, S.N. Ytterboe, H.M. Bozler, A.L. Thomson, and M.C. Cross, *Can. J. Phys.* **65** (1987) 1351.

[6] H.M. Bozler, Yuan Gu, Jinshan Zhang, K.S. White, and C.M. Gould, *Phys. Rev. Lett.* **88** (2002) 065302.