ELSEVIER

Physica B 284–288 (2000) 248–249

PHYSICA B

www.elsevier.com/locate/physb

NMR measurements of superfluid ^{3}He-A in cylindrical cell under rotation

O. Ishikawa[a], R. Ishiguro[b], K. Fukuda[c], Y. Sasaki[b], T. Takagi[d], T. Ohmi[b], T. Mizusaki[b,*], A. Marchenkov[e], J.C. Davis[e], R.E. Packard[e]

[a]*Graduate School of Science, Osaka City University, Osaka 558-8585, Japan*
[b]*Department of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan*
[c]*Meiji University of Oriental Medicine, Hiyoshi-cho, Funaigun, Kyoto 629-0392, Japan*
[d]*Department of Applied Physics, Fukui University, Fukui 910-8507, Japan*
[e]*Department of Physics, University of California, Berkeley, CA 94720, USA*

Abstract

We measured cw-NMR of superfluid ^{3}He-A in cylindrical cells with diameters of 0.1 and 0.2 mm under rotation. A new satellite signal was observed only in the 0.2 mm cell when the liquid was cooled through T_c under rotation but was not observed when it was cooled without rotation. The angular velocity of rotation is too low to create one vortex line in the cylinder and thus the satellite signal may be due to the spin wave of the Mermin–Ho texture.

Keywords: ^{3}He-A; NMR; Rotating superfluid; Texture

The textures of superfluid ^{3}He-A in a cylindrical sample cell have been studied [1]. We consider a case where the radius of the sample cell is about 10 times bigger than the dipole coherence length, ξ_D. Two possible candidates of texture in this case are the Pan-Am texture (P-A) and the Mermin–Ho (M–H) (see, for instance, Ref. [1]). Under a magnetic field which is bigger than the dipole field of 2 mT and is applied parallel to the cylindrical axis, the P-A is stable against the M–H when we include the dipole interaction. An important feature of the M–H is that it has a spontaneous macroscopic angular momentum along the cylindrical axis, which couples to rotation and thus may stabilize the M–H by rotation of the sample. Takagi [2] calculated the change of the textural structure and obtained the spin wave frequency as a function of rotation speed. He pointed out [3] that the rotation effect on the texture should be significantly altered if each pair has an intrinsic angular momentum, $\hbar$.

We investigated cw-NMR absorption spectrum of superfluid ^{3}He-A in cylindrical cells under rotation. The superfluid ^{3}He-A at 3.01 MPa was filled in bundles of parallel cylinders (about 150 tubes) with inner diameters of 0.1 and 0.2 mm and the direction of NMR field of $H_0 = 23$ mT, and the rotation axis was parallel to the cylindrical axis. We took measurements under rotation speed of about ± 1 rad/s.

We measured the spectrum without rotation for both 0.1 and 0.2 mm samples. Fig. 1(a) shows a typical absorption spectrum observed for 0.1 mm sample at $T = 0.78T_c$ and (b) and (c) are the calculated spectra for the P-A and the M–H, respectively, by using a local field approximation, convoluted by a measured field profile. The measured spectrum was distributed from the bulk frequency shift of the A-phase, $\Omega_A^2/2\omega_L$, to the Larmor frequency, $\omega_L = \gamma H_0$. The calculated spectra for both textures are not very different from each other but the observed spectrum is close to that of the P-A. Data for the 0.2 mm sample were very similar to data for the 0.1 mm sample. When we rotated the sample up to 1 rad/s, there was no significant changes in the spectrum for both samples. The texture in both samples may be the P-A.

* Corresponding author.
E-mail address: mizusaki@scphys.kyoto-u.ac.jp (T. Mizusaki)

0921-4526/00/$ - see front matter
PII: S0921-4526(99)02493-X

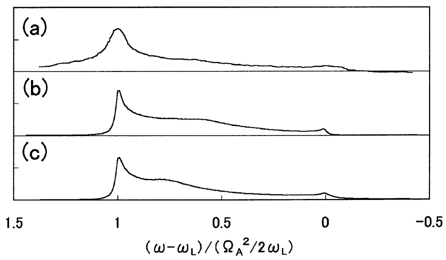

Fig. 1. NMR absorption spectra for the 0.1 mm sample: (a) observed spectrum at $T = 0.78T_c$, (b) calculated spectrum for the P-A, and (c) calculated spectrum for the M–H by using the local approximation.

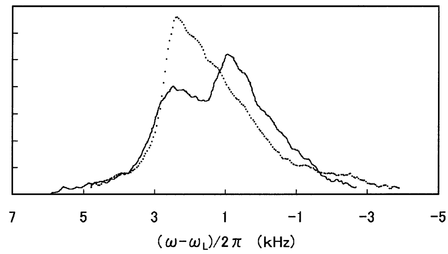

Fig. 2. NMR absorption spectra for the 0.2 mm sample at $T = 0.81T_c$. The solid curve is the spectrum cooled with rotation, and the dotted curve is without rotation.

Next, we cooled the sample to the superfluid phase under rotation. There was no change for the 0.1 mm sample but a new satellite signal appeared for the 0.2 mm sample. A typical spectrum at $0.81T_c$, where it was cooled under rotation of 0.88 rad/s through T_c, is shown by the solid curve in Fig. 2 and the dotted curve is the spectrum of the sample cooled without rotation. The 0.2 mm sample was located off the magnet center and the line width due to field inhomogeneity was about 4 kHz. Once this new texture was created in this way, it was very stable even though the rotation was stopped as far as the sample was kept in the superfluid state. The angular velocity of rotation was too low to create one vortex line in the cylinder. We calculated free energies for the M–H and the P-A under rotation and found that the M–H is more stable than the P-A above a certain rotation speed. Therefore the new texture should be the M–H and the texture for the 0.1 mm sample and the 0.2 mm sample cooled through T_c without rotation should be the P-A. We regard the spectrum to be composed of a rather sharp peak which comes from the spin wave around the central part of the M–H texture and a broad background from the rest of the texture. Based upon this assumption, we obtained $R_t^2(T)$ from the ratio of the frequency shifts of two peaks. The temperature dependence of $R_t^2(T)$ is fit to $R_t^2(T) = 0.503(1 - 1.65(1 - T/T_c))^2$ with a standard deviation of 0.036. There were large scatters due to the inhomogeneous broadening and we could not determine the rotation effect on the M–H predicted by Takagi. The critical rotation speed to stabilize the M–H against the P-A was estimated to be 0.8 rad/s for the 0.2 mm sample and 3.2 rad/s for the 0.1 mm sample. We have not yet measured the critical rotation speed but the estimation is consistent with our observation.

Acknowledgements

We acknowledge the support of a Japan–US Joint Project from the Japanese Society for the Promotion of Science and NEDO.

References

[1] D. Vollhart, P. Wölfle, The Superfluid Phases of Helium 3, Taylor & Francis, London, 1990.
[2] T. Takagi, J. Phys. Soc. Japan 65 (1996) 1722.
[3] T. Takagi, Czech. J. Phys. 46-S1 (1996) 51.