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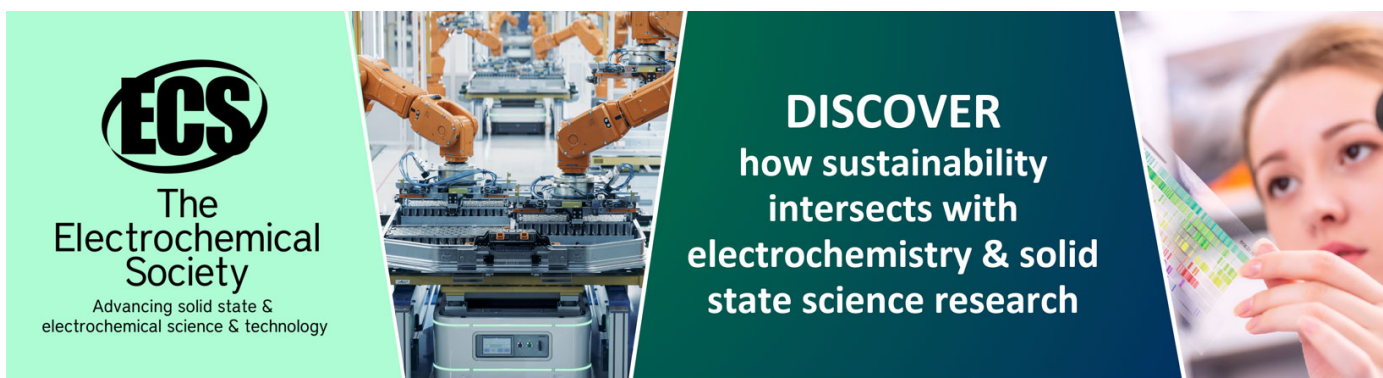
Pressure Dependence of the Longitudinal Resonance Frequency of ^3He Superfluid Phases in Aerogel

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Pressure Dependence of the Longitudinal Resonance Frequency of ^3He Superfluid Phases in Aerogel

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Abstract. Pulsed NMR measurements have been performed on superfluid ^3He within a 98% porosity aerogel over a pressure range of 8 to 26 bar. The aerogel sample is homogeneous and isotropic as indicated by *in situ* optical birefringence and, on similarly prepared samples, using SAXS characterization [1]. Two different superfluid phases are observed at low temperature. The two phases are identified as the same as the A and B-phases in pure ^3He , from tip angle measurement and the NMR equations of Leggett [2]. The pressure and temperature dependence of the longitudinal resonance frequency of each phase is reported in this article.

1. Introduction

NMR is a powerful tool for the determination of the order parameter structure of superfluid ^3He . The amplitude of the order parameter is proportional to the longitudinal resonance frequency given by the shift of the NMR spectrum from the Larmor frequency, ω_L , in a known texture. [3] Using the NMR relation of Leggett, Eq. 1, the two different pure superfluid phases were identified [3] as the Balian-Werthamer state (B-phase) and the Anderson-Brinkman-Morel state (A-phase). The ratio in Eq. 1 with the factor $5/2$, indicates the symmetry of the ABM and BW states where $\chi_{A,B}$ are the susceptibilities of the two phases and $\Delta_{A,B}$ are the average energy gaps.

In 1995 it was found that a modified form of superfluid ^3He exists within 98% porous silica aerogel [4, 5, 6], also exhibiting two different phases, although evidence for their structure has not yet been firmly established. Here we report the pressure dependence of the longitudinal resonance frequency of each of the two superfluid phases, $\Omega_{A,B}$, in a single highly isotropic and homogeneous aerogel of 98% porosity.

$$\left(\frac{\Omega_B}{\Omega_A}\right)^2 = \frac{5 |\Delta_B|^2 \chi_A}{2 |\Delta_A|^2 \chi_B} \quad (1)$$

2. Longitudinal Resonance Frequency Measurement

The 98% porous aerogel sample is a cylinder 5 mm long and 4 mm diameter, grown at Northwestern University. This sample is highly homogeneous and isotropic as indicated by optical birefringence, and SAXS measurements on similar samples.[1] Pulsed NMR was performed with the NMR field of 196 mT perpendicular to the cylinder axis. Two superfluid phases are indicated in Fig. 1. The liquid susceptibility is given as red circles in Fig. 1, after correction for the

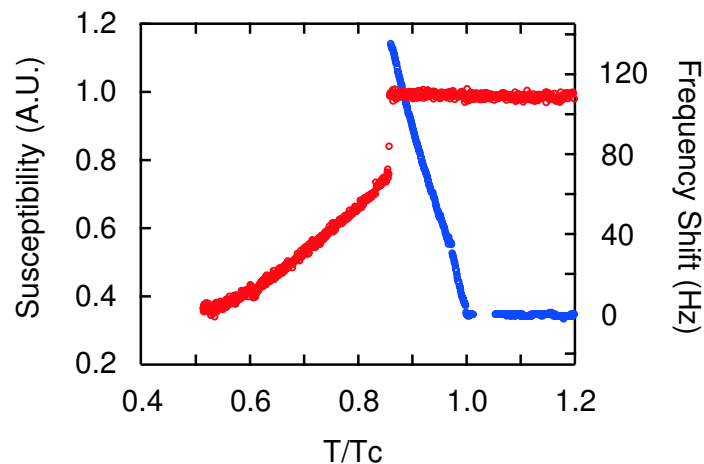


Figure 1. Susceptibility and frequency shift of the NMR spectrum versus reduced temperature at a pressure of 26.12 bar and a magnetic field of 196 mT. The normal to superfluid transition is $T_{ca} = 2.213$ mK.

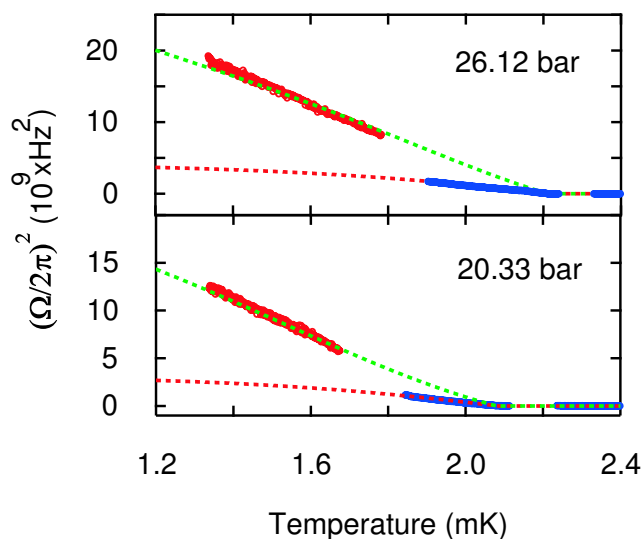


Figure 2. Longitudinal resonance of B and A-phases as functions of temperature at 26.12 and 20.33 bar. The dashed lines are the expected temperature dependence scaled from pure ^3He measurements. The ratio of these curves is consistent with the Leggett relation, Eq. 1, using measured values of the susceptibility and taking the gap ratio from measurements of the specific heat in a similar aerogel. [7, 8]

presence of a small bulk superfluid ^3He component and for the solid ^3He background. [5] The width of the transition between the two superfluid phases on warming is less than $3 \mu\text{K}$ delineated by a susceptibility jump. The high temperature phase with a constant susceptibility is an equal-spin-pairing state. Its frequency shift, $\Delta\omega_A$ shown by blue circles, defines the longitudinal resonance frequency, Ω_A , given by Eq. 2. NMR tip angle measurements, presented elsewhere,[9] are consistent with a dipole locked configuration. Similarly, our tip angle measurements for the low temperature phase, [9] identify this phase as the BW state with Leggett angle of 104° as

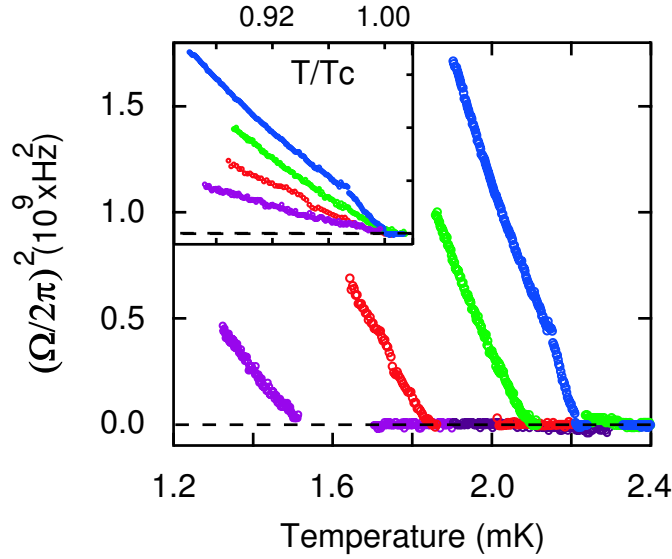


Figure 3. Longitudinal resonance frequency of the A-phase versus temperature for various pressures: blue, 26.12 bar; green, 20.33 bar; red, 14.04 bar; purple, 8.12 bar.

noted previously by Dmitriev *et al.* [10]. For our sample geometry a wall pinned mode, $\vec{l} \perp \vec{H}$, is clearly observed in the spectrum of the low temperature phase having a frequency shift $\Delta\omega_B$ from which we have determined Ω_B in that phase using Eq. 2.

$$\Omega_A^2 = 2\omega_L\Delta\omega_A \quad \Omega_B^2 = \frac{5}{2}\omega_L\Delta\omega_B \quad (2)$$

The squares of the A and B-phase longitudinal resonance frequencies are given in Fig. 2 at 26.12 and 20.33 bar. For each pressure, the red dashed line is scaled from bulk A-phase data reported by Schiffer *et al.* [11] The green dashed line is calculated from the scaled bulk A-phase data and the NMR relation of Leggett, which matches well with the B-phase data from our experiment. The ratio of the longitudinal resonances in the two phases satisfy the NMR relation of Leggett for ABM and BW states, Eq. 1. to an accuracy better than 5% over the temperature interval of the measured B-phase, confirming the identity of the high temperature phase as the ABM state with a dipole-locked texture.

3. Pressure Dependence of the Longitudinal Resonance Frequency

Below 20 bar the $\vec{l} \perp \vec{H}$ component of the B-phase spectrum is not easily resolved and we cannot calculate the longitudinal resonance frequency of the B-phase. However, the A-phase longitudinal resonance frequency has been measured for multiple pressures as is shown in Fig. 3.

The slope of the A-phase longitudinal resonance frequency near T_{ca} , $\partial\Omega_A^2/\partial(T/T_{ca})$, was measured at different pressures and is compared with previous measurements in pure ^3He in Fig. 4. The purple and red squares are pure ^3He measurements performed at Northwestern [12] and Stanford [11] which are a linear function of pressure. The green squares are the slopes of the A-phase longitudinal resonance frequency for the A-phase in our aerogel sample. Since the order parameter amplitude is proportional to the longitudinal resonance frequency these data suggest that there is a critical pressure close to $P = 0$, where the order parameter amplitude goes to zero.

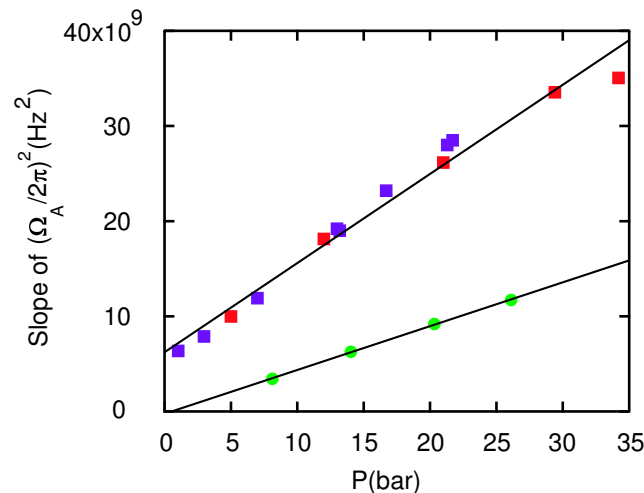


Figure 4. Comparison of A-phase longitudinal resonance frequency slopes near T_c as a function of pressure between pure and aerogel superfluid ^3He .

4. Summary

Pulsed NMR measurements of A and B-phase longitudinal resonance frequencies have been performed on superfluid ^3He in a 98% porosity silica aerogel with high homogeneity and isotropy. The results match the NMR relation of Leggett. This provides strong evidence that these phases are respectively the ABM and BW states, *i.e.* the same as for pure ^3He . The slopes of the A-phase longitudinal resonance frequencies near T_{ca} are a linear function of pressure which, in this aerogel sample, extrapolate to a critical pressure near $P = 0$ where the order parameter appears to go to zero.

5. Acknowledgement

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6. References

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