The Equilibrium A-B Transition in Low Density Aerogels

Douglas D. Osheroff and James E. Baumgardner

Department of Physics, Stanford University, Stanford, CA 94305-4060, USA

We have measured in detail the NMR spectra of superfluid $^3$He inside two different silica aerogels, one with a porosity of 99.3% and the other 98.6%. From these spectra, we are able to determine the equilibrium A-B transition temperatures in both aerogel samples as a function of hydrostatic pressure. We find that the slope of the reduced A-B transition temperature, $1 - T_{AB}/T_c$, vs. pressure is only about one third that seen for the bulk A-B transition, despite the fact that $T_c$ for the two samples is suppressed very modestly, by only 4% and 8% at 34 bars. We argue from this that the presence of the aerogel stabilizes an equal-spin pairing phase which is distinct from that stable in the bulk.

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1. INTRODUCTION

This laboratory has long wanted to measure how the presence of low-density silica aerogels might shift the A-B transition temperature, as this would provide a measure of how different p-wave condensate symmetries are affected by the presence of impurity scattering centers. Superfluid $^3$He should be sensitive to such differences in depairing, since in the bulk, even at very low temperatures, the difference in condensate free energies for the A and B phases is only a few percent of the total condensate free energy. However, we have found that the interface between the A-like and B-like superfluid $^3$He phases is pinned in low density silica aerogels at virtually all temperatures. This has made it very difficult to determine the equilibrium transition temperature, $T_{AB}$, and even to observe the A-B transition at all on warming in many instances.
2. RESULTS

We have recently reported\(^2\) an analysis of NMR spectra obtained on warming and cooling of such samples in which we have warmed to a well-defined maximum temperature a variable amount below \(T_c\), and cooled back to a temperature well below \(T_c\) (1.8 mK at 34 bars) at which it was possible to compare the recorded spectra with all A-like and all B-like spectra obtained by cooling directly to this temperature from above \(T_c\) and warming to it from well below the first order \(A\)-\(B\) transition observed on cooling. In these measurements it was found, depending upon how close one warmed to \(T_c\), that the spectra on cooling were composites of the two pure-phase spectra, with the relative weights of the two spectra dependent upon how close to \(T_c\) the sample was warmed. By extrapolating the A-like fraction to zero, we obtained one possible measure of the \(A\)-\(B\) transition temperature. This value was in all cases nearly identical the temperature obtained by plotting the total sample magnetization\(^3\) vs. temperature, and identifying the point at which the magnetization began to rise more quickly than the typical B-like linear behavior seen at lower temperatures upon warming. This temperature, which we have referred to as \(T_{AB,\text{warming}}\), is not necessarily the equilibrium value, however, but only the temperature at which the \(A\)-\(B\) interface first began propagating into the aerogel.

We needed a direct measure of the thermodynamic \(A\)-\(B\) phase transition temperature, the temperature at which that A and B condensate free energies are equal. Since the square of the longitudinal resonance frequency times the susceptibility is proportional the square of the BCS energy gap (and hence the condensate free energy)\(^4\) in both the A and B phases, one can determine the ratio of the condensate free energies from the longitudinal resonance frequencies:\(^5\):

\[
\frac{F_B}{F_A} = \frac{2 \chi_B}{5 \chi_A} \left( \frac{\Omega_B}{\Omega_A} \right)^2
\]

We could not measure the longitudinal resonance frequency directly in our aerogel samples, but in the high-field regime, it is related to the maximum NMR frequency shift possible in each phase:

\[
\left( \frac{\Omega_B}{\Omega_A} \right)^2 = \frac{\Delta \omega_{B,\text{max}}}{\Delta \omega_{A,\text{max}}}
\]

The NMR spectra inside the aerogel are typically very broad. However, to ensure that the maximum spectral frequencies we measured were indeed the maximum values possible, we studied the spectra as a function of the orientation of the static magnetic field. Typical A-like phase spectra are shown