Stability of the A-like Phase of Superfluid $^3$He in Aerogel with Globally Anisotropic Scattering

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It has been suggested that anisotropic quasiparticle scattering will stabilize anisotropic phases of superfluid $^3$He contained within highly porous silica aerogel. For example, global anisotropy introduced via uniaxial compression of aerogel might stabilize the axial state, which is called the A-phase in bulk superfluid $^3$He. Here we present measurements of the phase diagram of superfluid $^3$He in a 98% porous silica aerogel using transverse acoustic impedance methods. We show that uniaxial compression of the aerogel by 17% does not stabilize an axial phase.

When disorder is introduced into superfluid $^3$He by way of high porosity silica aerogel a metastable A-like phase appears on cooling $^{2,3,4,5,6}$ This phase is thought to be like the A-phase in bulk superfluid $^3$He, known to be the axial $p$-wave state. At sufficiently low temperatures this metastable phase undergoes a transition to an isotropic superfluid phase similar to the isotropic state observed in bulk $^3$He, the B-phase. However, a distinct transition from the B-like phase to the A-like phase in aerogel is not seen upon warming. Tracking experiments $^{3,4,5}$ have shown that coexistence of A-like and B-like phases occurs in a narrow window of temperature, $\approx 20 - 50 \mu K$, near the normal-to-superfluid transition temperature in aerogel, $T_c$. This is contrary to the expectation that the B-phase should be stable at all pressures and temperatures if the disorder introduced is homogenous and the scattering is isotropic $^7$. On the other hand, it has been predicted that scattering anisotropy from the strands of aerogel might destabilize the B-like phase in favor of the A-like phase $^8$.

Pursuing this idea, Vicente et al. $^9$ suggested that the introduction of global anisotropy into aerogel, for example by uniaxial strain, might increase the stability of the A-like phase. Recent calculations $^5$ have shown that uniaxial anisotropy (achieved for example by compression along one axis) should stabilize the axial state, whereas radial anisotropy (radially compressed or radially reduced by preferential shrinkage during growth) might stabilize the polar state. Our previous result $^5$ for $^3$He in aerogel with preferential radial shrinkage suggest a phase with increased stability, but the aerogel was not rigidly adhered to the transducer surface so there is some question as to whether or not this was an effect intrinsic to superfluid $^3$He in aerogel. In this paper we present our measurements of the phase diagram for superfluid $^3$He in a sample of 98% porosity silica aerogel grown directly on the surface of a transducer and then subjected to uniaxial strain of 17%.

We used transverse acoustic impedance measurement $^{2,3,9}$ at the third harmonic (17.6 MHz) of an $AC$-cut quartz piezoelectric transducer, 0.84 cm in diameter. The impedance was measured using a frequency modulated RF-bridge, described elsewhere $^{10}$. It has been shown $^{11}$ that for aerogel grown directly onto the transducer surface, the measured impedance is sensitive to all phase transitions through coupling of the shear transducer to the superfluid and is coincident with transitions in the interior of the aerogel. We grew our aerogel sample in the open space between two parallel transducers separated by two spacer wires, 0.0305 cm diameter, held under tension from a stainless steel spring. Fig. 1. Two additional spacer wires of smaller diameter, 0.0254 cm, were placed along side and between the larger ones before aerogel was grown to fill the entire assembly.

The aerogel was synthesized at Northwestern University via a one-step sol-gel process followed by supercritical drying $^{12}$. The density was controlled by the ratio of the reactants during the synthesis and was measured after drying to be 97.8% porous. After drying, the excess aerogel was removed, leaving only the aerogel between the two parallel transducers such that their outer surfaces could be exposed to bulk $^3$He. Next, the 0.0305 cm diameter spacers were removed, maintaining tension with the spring, such that the aerogel was com-

FIG. 1: Assembly diagram for the support structure that allows the aerogel to be grown directly between two quartz transducers and then compressed in situ. After aerogel growth and compression a glass sleeve on the outside of the assembly was epoxied in place.
The bulk superfluid transitions are \( T_c \) and \( T_{AB} \) and are very distinct. The aerogel phase transitions, \( T_{ca} \) and \( T_{ABa} \), are more spread out, but are easier to identify in the derivative of the acoustic response with respect to temperature, in (b). Note that the warming and cooling trace do not match up in the temperature interval between \( T_{ca} \) and \( T_{ABa} \). On cooling, this region corresponds to the supercooled A-like phase, whereas on warming, this corresponds to the B-like phase.

The transition width is approximately 40 \( \mu \)K, similar to that of uncompressed aerogel\(^{15}\). The dashed vertical lines are our estimate of the precision with which we can independently identify \( T_{ca} \) which overlaps the coexistence region of A-like and B-like phases.

Gervais \textit{et al.}\(^13\) and Vicente \textit{et al.}\(^16\) performed tracking experiments by warming up close to, but not through, the aerogel superfluid transition temperature, \( T_{ca} \). After stopping at a ‘turn-around’ temperature the samples were then cooled again to look for an A-like to B-like transition. In this way it is possible to find the warming transition and how close the turn-around temperature must be to the critical temperature, \( T_{ca} \), to observe it. The magnitude of the impedance change is a measure of the amount of superfluid undergoing the A-like to B-like transition. We performed these tracking experiments at 25 bar in order to determine the window of coexistence of A-like and B-like phases in uniaxially compressed aerogel. We integrated the area of the dip in the derivative of the acoustic response with temperature and plot this as a function of the ‘turn-around’ temperature in Fig. 3 at 25 bar. The coexistence region is \( \approx 40 \mu \)K which, to within our precision, is within 50 \( \mu \)K of \( T_{ca} \) similar to that reported earlier\(^{10}\) for nominally isotropic aerogel.

In Fig. 4, we show the superfluid transitions, \( T_{ca} \), as well as the amount of supercooling in our uniaxially compressed aerogel compared to that of Gervais \textit{et al.}\(^13\) and Nazaretski \textit{et al.}\(^4\). The similarity is striking given the significant amount of global anisotropy in our sample. The only apparent difference between our results on axially compressed aerogel and previous work is the increase in the supercooling of the A-like phase at pressures below 20 bar. This does not bear directly on the stability of the A-like phase, but suggests that the mechanism for nucleation of the B-phase is suppressed at lower pressures for uniaxially anisotropic aerogel. We have also
found that the signature of the A-like to B-like transition becomes smaller as the pressure is decreased until it becomes difficult to measure below 12 bar. Although we find that uniaxial compression of the aerogel does not enhance phase stability, nonetheless we note that there are recent reports that the orientation of the superfluid order parameter can be influenced by anisotropy.\cite{10-13}

In summary, we find that the introduction of global anisotropy from uniaxial compression of 17% does not stabilize the A-like phase of superfluid $^3$He in aerogel, in contrast to various suggestions.\cite{6,8} The region of coexistence of the A-like and B-like phases is approximately 40 $\mu$K and indistinguishably close to the normal-to-superfluid transition, nearly the same as that measured previously in uncompressed aerogel.\cite{3,6} Consequently, it appears that uniaxial strain does not stabilize an A-like phase, or for that matter any phase, in aerogel. The pressure versus temperature phase diagram is remarkably similar to uncompressed aerogel, except for increased supercooling at low pressures in the range, 12 - 20 bar.

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