Loss of Memory in 'Dirty' Superfluid ^{3}He

G. Gervais [a,1], K. Yawata [a], N.Mulders [b], and W.P. Halperin [a]

[a] *Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208*

[b] *Department of Physics and Astronomy, University of Delaware, Newark, DE 19716*

Abstract

The transition between the A and B superfluid phases of ^{3}He is first order, and the A-phase has been known to supercool far into the region where the B-phase is thermodynamically stable. The extent of the supercooling strongly depends on whether the cooling originates from above, or from below the normal-to-superfluid transition. For the latter, the supercooling has a 'memory' of the prior warming history. We have studied the nucleation of the B-phase for pure ^{3}He and for a superfluid constrained to a dilute silica aerogel of 98% porosity. Interestingly, we have found that the nucleation of the aerogel B-phase shows, unlike the pure case, no memory, even though large supercooling of the aerogel A-phase is observed.

Key words: superfluid ^{3}He; nucleation; aerogel

The transition between the A and B superfluid phases of ^{3}He is first order with a small but observable latent heat. Upon cooling, the AB-transition is known to exhibit large supercooling; but exactly which nucleation mechanism plays the key role remains one of the significant unsolved problems in low-temperature physics [1]. The very large critical radius needed for the nucleation of the B-phase, $R_c \sim 1\ \mu m$, is incompatible with nucleation scenarios driven by thermal fluctuations alone[2]. While heterogeneous mechanisms, such as surface roughness [3], radiation[2] or vibration[3,4] have been shown to a play a role, there is yet no consensus about which of these dominate the nucleation process.

It is now generally accepted that there are two superfluid phases in superfluid ^{3}He constrained to low-density aerogels, and their magnetic properties are very similar to that of the bulk A and B phases [5–7]. This opens up possibilities to study the nucleation of the aerogel B-phase, and its comparison with pure superfluid ^{3}He-B could give insight to the role played by heterogeneous mechanisms.

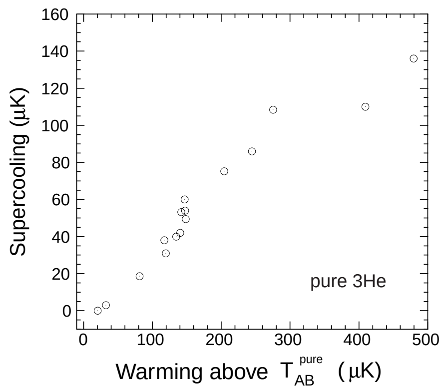

Fig. 1. Memory effect for the supercooling of the pure A-phase. The amount of supercooling is defined by the difference of the AB-transition temperatures measured on cooling and warming. The x-axis shows the amount of warming above the equilibrium BA-transition prior to cooling (secondary nucleation).

Primary nucleation of the B-phase, from the supercooled A-phase, occurs on cooling from the normal state, i.e. there has been no prior history of the B-phase. Secondary nucleations occurs on supercooling of the A-phase after a primary nucleation, but without having warmed to the normal state. In this case, the

1 E-mail: g-gervais@northwestern.edu

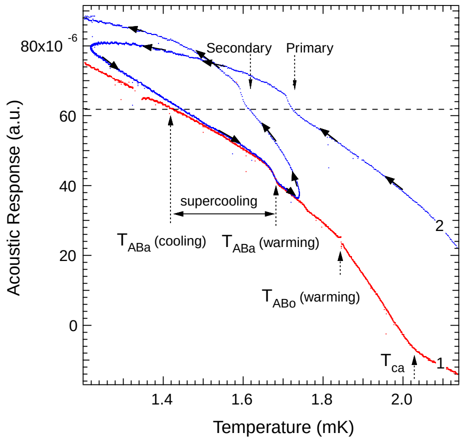

Fig. 2. Transverse acoustic response showing primary and secondary nucleation at 28 bars and 1.8 kG. The trace labeled #1 is a reference taken on slow warming. The trace #2 shows the cooling originating from the normal state and the primary nucleation, and a secondary nucleation experiment. The thermometry scale is only for warming (see text).

supercooling of the A-phase in pure ^{3}He depends on the degree to which the liquid was warmed above the BA-transition. This was first noted in 1971 by Osheroff at melting pressure in a Pomeranchuck cell[8]. Figure 1 shows a plot of the recorded supercooling in our experimental cell (see Ref.[7]) for the pure A-phase versus the amount of warming above the BA-transition[6], quantitatively similar to the original report [8]. Primary nucleation at the same pressure and field was typically of order $\sim 300\mu K$. The trend of the data clearly shows that supercooled ^{3}He retains a memory of the prior warming history. This has been attributed to remnants of B-phase persisting above the BA-transition. Suggestions of candidates for these are trapped B-phase at the cell walls, the so-called 'Lobster-pot'[1], or trapped B-phase around magnetic dirt [9].

In 'dirty' superfluid ^{3}He, it has been shown [10,5] that the aerogel A-phase also exhibits large supercooling similar to that of the pure A-phase. Would secondary nucleation of the aerogel B-phase retain a memory of its prior history? Figure 2 shows the transverse acoustic response at 28 bars and 1.8 kG in our acoustic cavity, which is used here to determine the aerogel AB-transition on cooling and warming (see ref.[5,7]). The trace labeled #1 is a reference taken with slow warming and the trace #2 shows the secondary nucleation experiment. The thermometry on cooling is lagging the true temperature of the ^{3}He in the cell, hence not accurate in this plot for trace #2. However, we can use the acoustic response amplitude as an internal thermometer and the temperatures of the transition on cooling can be estimated to within ~ 20 μK. This was verified to be valid by comparing it with a very slow cooling experiment where the thermometer was in thermal equilibrium with the liquid in the cell.

Let's consider the trace #2. Upon cooling from the normal state, after primary nucleation of the aerogel B-phase, the experimental cell was warmed up to a temperature 55 μK higher than the BA-transition (T_{ABa}), yet far less than T_{ca}. It was then cooled again and the secondary nucleation event recorded. Both the primary and secondary nucleation are found at the same amplitude on the acoustic trace given by the horizontal dashed line, showing that they supercooled by the same amount, ~ 150 μK. In contrast, pure superfluid ^{3}He-A shows very little supercooling, ~ 15 μK, when cooled from a temperature just above the BA-transition, as shown in Fig.1. *This demonstrates that 'dirty' superfluid ^{3}He has lost its memory of the warming history.*

The presence of a memory for nucleation is reminiscent of heterogeneous nucleation mechanisms. However, we cannot conclude that the absence of memory in the aerogel superfluid indicates homogeneous nucleation. It has been shown in Ref.[6] that the bulk and aerogel superfluid nucleate independently, and that proximity coupling does not act as a nucleation source in either superfluid. Since our aerogel sample is only in contact with the transducer walls and two spacer wires, it is possible that there are no dirty B-phase remnants persisting above T_{ABa} in the aerogel sample, and the only trapped B-phase near inhomogeneities at the transducer walls are of a pure superfluid type, hence not triggering the nucleation of the dirty B-phase.

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