Pulsed NMR experiments in superfluid ^{3}He confined in aerogel

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Abstract

Pulsed NMR experiments have been performed in both B and supercooled A phases of superfluid ^{3}He confined within aerogel. The tipping angle dependencies of spin precession frequency in B-like phase of superfluid ^{3}He in aerogel are found to be quite different for the case of pure ^{3}He and for the cell preplated with ^{4}He. A sharp increase of the frequency shift for the tipping angles greater than 104° was observed in ^{4}He preplated aerogel as it is expected for the B-phase structure of the order parameter. The dependence of the frequency versus the tipping angle in supercooled A-phase is similar for both pure ^{3}He and ^{4}He preplated aerogel.

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

Introdiction

Liquid ^{3}He confined in low density aerogel provides a system for studies of the influence of impurities on superfluidity. Evidence of superfluidity of ^{3}He in aerogel was first reported in [1,2] and in recent works the superfluid phase diagram was established [3,4]. Two superfluid phases were found to exist which are suggested to be analogous to A and B phases in the bulk ^{3}He. The phase diagram is believed to be the same for the cases of ^{4}He preplated aerogel and for pure ^{3}He sample. In the latter case there are few monolayers of solid ^{3}He absorbed on the aerogel strands. These layers exhibit Curie-Weiss magnetization which rapidly grows with decreasing the temperature [2]. However, due to fast exchange [5] magnetizations of the adsorbed solid and liquid phases precess with the same frequency which is defined by their magnetic moments and frequencies.

Most of the experiments on aerogel have utilized samples with porosity near 98% (as in this report) and have been done using CW NMR, acoustic techniques, torsion oscillator or vibrating wire. Results of pulsed NMR were reported only in [2,6]. According to [2] the frequency of a free induction decay signal (FIDS) is shifted from the Larmor value for small tipping angles (β). In pure ^{3}He this shift decreases with the increase of the angle and vanishes for $\beta \geq 40°$. We present here the results of systematic pulsed NMR investigations of superfluid ^{3}He in aerogel done for both pure ^{3}He sample and for ^{4}He preplated aerogel.

Experiments

The aerogel sample had a form of a cylinder (diameter = length = 5 mm) with the axis oriented along the external steady magnetic field. The sample was situated inside epoxy cell so that there were small gaps (0.15 mm) between aerogel and internal surfaces of the cell. The NMR coil was wound outside of the cell and was thermally attached to the mixing chamber of dilution refrigerator. Standard pulsed NMR technique was used: FIDS was recorded after a short tipping radiofrequency pulse. Experiments were done at pressure of 25.5 bar and in magnetic fields from 142 Oe up to 1.06 kOe (corresponding NMR frequencies are 461 kHz and 3.45 MHz). The obtained results are found to be qualitatively the same for all NMR frequencies.

The form, duration and frequency of FIDS were

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found to change essentially below some temperature, which we attribute to the superfluid transition temperature of ^{3}He in aerogel ($T_c^a = (0.76 \pm 0.02)T_c$, where T_c is the superfluid transition temperature of bulk ^{3}He). The mean frequency of the FIDS for small tipping pulses ($\leq 20°$) below T_c^a is shifted from the Larmor value. This shift increases with decreasing temperature and it is positive for B-phase and is negative for supercooled A-phase as it was expected from the previous experiments [4,6]. At larger β the FIDS frequency changes and in B-phase starts essentially to depend on time. Consequently, in order to get some quantitative characteristic, we extrapolated the dependence of the frequency on time to the initial moment.

The case of pure ^{3}He in aerogel. B-phase: The obtained dependencies of FIDS frequency on β are shown on Fig.1 (here results of Fourier transform of FIDS in B-phase are also shown in order to compare them with [2]). It is seen that in B-phase our results do not agree with the results of [2] which presumably also have been obtained in B-phase. Rather complex tipping angle dependence is probably due to the texture of the order parameter inside aerogel. It is known [7] that for bulk ^{3}He in restricted geometry a large tipping pulse can result in a textural transition into Brinkman-Smith mode [8]. In our experiments no evidence of such transition was observed, that means that the texture is defined by the aerogel volume (not by the cell walls) and is more rigid than expected.

The case of ^{4}He preplated aerogel. B-phase: Surprisingly, in B-phase the obtained results qualitatively differ from the case of pure ^{3}He sample (Fig.2). No evidence of the textural transition were also observed, but clear kink at the dependence of the FIDS frequency on the tipping angle at $\beta \approx 104°$ was found. Note that the frequency dependence on β vanishes at $T = T_c^a$, therefore this effect can not be attributed to small amount of bulk ^{3}He which is present in our cell. The observed behavior is an additional confirmation of the suggestion that the low temperature superfluid phase of ^{3}He in aerogel is B-phase. We can also conclude that the texture of the order parameter depends on the presence of solid ^{3}He layer. The latter assumption agrees with our measurements of the kinetics of A-B phase transition of ^{3}He in aerogel [9].

Experiments in supercooled A-phase: The obtained results for both (pure ^{3}He and ^{4}He preplated aerogel) cases are similar (Fig.1 and Fig.2). Negative frequency shift is seen for small tipping angles and FIDS frequency gradually increases with the increase of β. Further theoretical studies are necessary to understand such a behavior.

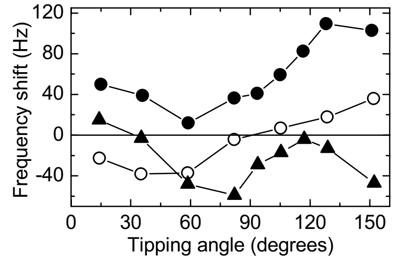

Fig. 1. FIDS frequency versus the tipping angle for the case of pure ^{3}He in aerogel. H =284 Oe. Solid symbols: B-phase, $T = 0.72T_c^a$ (triangles: maximum of Fourier transform of the FIDS, circles: extrapolation to the initial moment). Open symbols: supercooled A-phase, $T = 0.88T_c^a$. (for the better view results for A-phase are multiplied by a factor of 5).

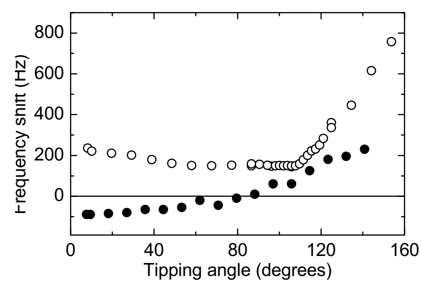

Fig. 2. The case of ^{4}He preplated aerogel. FIDS frequency versus the tipping angle. H =1.01 kOe. Open symbols: B-phase, $T = 0.83T_c^a$ Solid symbols: supercooled A-phase (for the better view results for A-phase are multiplied by a factor of 5).

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