Experiments on A-like to B phase transitions of ^{3}He confined to aerogel

Vladimir V. Dmitriev [a], Ivan V. Kosarev [a,1], Norbert Mulders [b], Vladislav V. Zavjalov [a], Dmitry Ye. Zmeev [a]

[a] *Kapitza Institute, Kosygina str. 2, Moscow, 119334, Russia*
[b] *Department of Physics and Astronomy, University of Delaware, Newark, Delaware 19716 USA*

Abstract

We have done pulsed and CW NMR studies of A-like to B phase transition in superfluid ^{3}He confined within aerogel with 98% porosity. The experiments were performed at pressure of 25.5 bar and in magnetic field of 284 Oe and 1 kOe. A kinetics of the transition is found to be different for pure ^{3}He in aerogel and for the cell preplated with ^{4}He.

Key words: superfluidity; helium-3; aerogel;

Since the first observation of the superfluidity of ^{3}He in aerogel [1], one of the intriguing questions concerning this system is what superfluid phases are realized there. The NMR has been widely used to investigate this problem since the first experiment of Sprague et al. [2]. Recent NMR experiments [3–5,7] together with acoustic measurements [6] resulted in establishing of a phase diargam of superfluid ^{3}He in aerogel and the identification of the superfluid phases. Unusual feature of this diargam is that along with B-phase so called supercooled A-like phase can exist in wide range of temperatures below the temperature of the superfluid transition (T_c^a).

One common issue which complicates NMR experiments in aerogel is a solid layer of ^{3}He covering aerogel strands. Its magnetic moment results in a large contribution to the overall NMR signal. It is possible to replace ^{3}He localized on the strands by adding small amount of spinless ^{4}He. We present here results of our studies of the transition between supercooled A-like and B phases in aerogel done in both ^{4}He preplated aerogel and pure ^{3}He.

We start from the case of ^{4}He preplated aerogel. Fig. 1 shows NMR spectra taken upon cooling from the normal phase. Below $T_c^a \approx 0.76T_c$ (where $T_c = 2.37mK$ is the temperature of the superfluid transition in bulk ^{3}He) the NMR line starts to broaden and shifts in negative direction relative to the Larmor frequency (ω_L) (these curves are not shown). On further cooling, a positively shifted tail appears and grows while the integral intensity of the negatively shifted part of the spectrum starts to decrease. At some temperature $T^* \approx 0.71T_c^a$ the negative part of the spectrum vanishes. A behavior of the NMR line on warming from below T^* to T_c^a qualitatively replicates the temperature dependence of the positive tail of the signal on cooling but negatively shifted part of the NMR line does not appear. The same behavior (i.e. clear dependence on the direction of the temperature sweep) of the mean frequency of free induction decay signal (FIDS) was also observed in our pulsed NMR experiments done at the same conditions.

The negatively shifted NMR line was observed earlier by Barker *et al.* [5] below T_c^a on cooling. On further cooling down to T_{AB}^a the line became broader with much of the signal shifted below ω_L. Then, at T_{AB}^a abrupt changes in a shape of the line were observed: the negatively shifted part of the spectrum suddenly vanished and simultaneously a long positive tail appeared. A magnetization of the ^{3}He was found to be nearly constant in a region between T_{AB}^a and T_c^a and this fact

[1] E-mail:ivan@kapitza.ras.ru

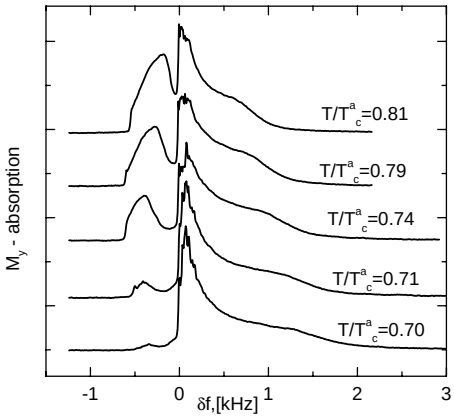

Fig. 1. CW NMR spectra recorded on cooling of ^{3}He in ^{4}He preplated aerogel (P=25.5 bar, H=284 Oe)

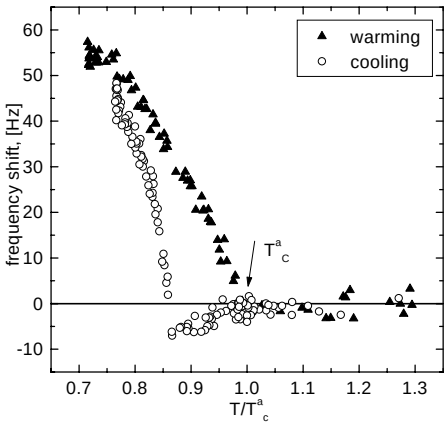

Fig. 2. The frequency shift on cooling and subcequent warming calculateted as the mean FIDS frequency (P=25.5 bar, H=284 Oe, No ^{4}He used).

allows to assume the presence of A-phase in a system. Correspondingly the sudden change in the NMR line was attributed to a phase transition of ^{3}He from supercooled A-like into B-phase. However, the origin of the negative frequency shift remains unclear. To explain it one should suggest that the mean angle between vectors **l** and **d** of the order parameter is close to 90 degrees [5]. It does not look favorable due to an increase of the dipole energy. If following [5] we assume that the negative tail is due to the presence of the supercooled A-phase, then according to our data the transition from supercooled A to B phase is stretched over broad region of temperatures.

In the case of pure ^{3}He we used only pulsed NMR technique and similar results were obtained. The temperature dependence of FIDS frequency obtained on warming from low temperatures and subsequent cooling is shown on Fig.2 where points were taken within one minute interval. It could be seen that on cooling below T_c^a the negative frequency shift appears.

However, further investigations showed that there is a qualitative difference between cases of pure ^{3}He and ^{4}He preplated aerogel. In the latter case the shape of the CW NMR line (as well as the frequency of FIDS in pulsed NMR experiments) was found to be stable in the whole range of temperatures between T_c^a and T^*. It means that at fixed temperature the relative amounts of the B- and A-like phases remained constant. In the case of pure ^{3}He the state with negative frequency shift was found to be unstable: at fixed temperature the frequency shift grows to the positive value which is close to that which we measure during warm up from low temperatures. The rate of this change strongly depends on temperature: it is found to be several hours at $T/T_c^a \approx 0.9$ and decreases down to several minutes at $T/T_c^a \approx 0.8$ (i.e. most of the points at Fig.2 taken on cooling not correspond to the equilibrium state).

The performed experiments show that the kinetics of the assumed A-B phase transition on cooling depends on whether ^{4}He is used for preplating aerogel. The results obtained are similar for both values of the external magnetic field (284 Oe and 1.0 kOe) which we used in our experiments. In ^{4}He preplated aerogel our results differ from those of Barker *et al.* [5] in a magnitude of the temperature width of the transition. One of the possible explanations is an inhomogeneity of the aerogel sample.

Acknowledgements

We are grateful to J.Parpia and I.Fomin for stimulating discussions. The research was supported by the CRDF (Grant No. RP1-2098) and by the RFBR (Grants No. 00-02-17514 and 00-15-96574)

References

[1] J.V.Porto, J.M.Parpia, Phys.Rev.Lett. **74** (1995) 4667.

[2] D.T.Sprague, T.M.Haard, J.B.Kycia, M.R.Rand, Y.Lee, P.J.Hamot, W.P.Halperin, Phys.Rev.Lett. **75** (1995) 661.

[3] D.T.Sprague, T.M.Haard, J.B.Kycia, M.R.Rand, Y.Lee, P.J.Hamot, W.P.Halperin, Phys.Rev.Lett. **77** (1996) 4568.

[4] H.Alles, J.J. Kalpinsky, P.S.Wootton, J.D.Reppy, J.H.Naish, J.R.Hook, Phys.Rev.Lett. **83** (1999) 1367.

[5] B.I.Barker, Y.Lee, L.Polukhina, D.D.Osheroff, L.W.Hrubesh, J.F.Poco, Phys.Rev.Lett. **85** (2000) 2148.

[6] G.Gervais, T.M.Haard, R.Nomura, N.Mulders, W.P. Halperin, Phys.Rev.Lett. **87** (2001) 035701-1.

[7] V.V.Dmitriev, I.V.Kosarev, N.Mulders, V.V.Zavjalov, D.Ye.Zmeev, this conference.