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Acoustic spectroscopy of superfluid ^{3}He in aerogel in the presence of a magnetic field

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We have constructed a silver alloy cell to investigate low frequency sound propagation in ^{3}He-filled aerogel at various magnetic fields. In this apparatus, two sound modes were observed in the superfluid phase. We observed both the first sound-like mode (fast mode) which is a compression wave also seen in the normal state and the second sound-like mode (slow mode) which is attributed to the out-of-phase oscillation of the superfluid and normal components of ^{3}He clamped to the aerogel matrix. The values of T_c and ρ_s can be extracted from the analysis of these two modes. In addition, a Helmholtz resonance provides an in-situ signature of the bulk superfluid transition and allows us to also determine the bulk ρ_s. By measuring these quantities over a range of applied magnetic fields we hope to explore the P,T,H phase diagram of ^{3}He in aerogel.

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The presence of aerogel has a significant effect on the character of the superfluid transition in ^{3}He. A number of publications [1,2] have revealed a modification of the phase diagram of helium confined to the aerogel matrix. It has been shown, that superfluid ^{3}He supports two modes of sound propagation when confined to high-porosity aerogels [3,4]. These modes can be interpreted in the framework of the two-fluid hydrodynamics model where the aerogel contributes to the density of the normal fluid component [5]. The first sound-like mode (fast mode) is a compression wave, and is also observed in the normal fluid state. This mode has a higher propagation speed and arises from the in phase oscillation of the silica matrix and the nor-

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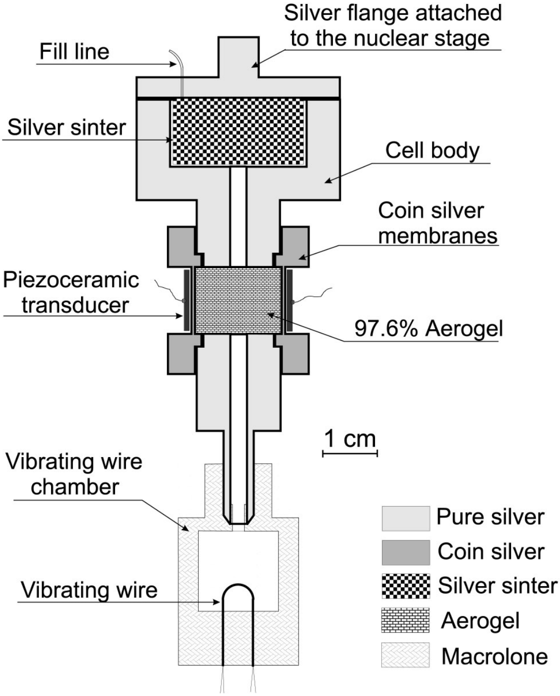

Fig. 1. Schematic drawing of the experimental cell used in low frequency sound experiments. For more details see text.

malfluid component with the superfluid component. The second sound-like mode (slow mode) is attributed to an out of phase oscillation between the aerogel with the normal fluid component clamped to it and the superfluid component.

We used low frequency CW sound propagation to probe the behavior of ^{3}He. Fig. 1 is the schematic representation of the cell used in the experiments. The body of the cell consists of two parts. The upper part is made from pure silver because of its small specific heat in the presence of a magnetic field. The sound is coupled to the ^{3}He fluid through coin silver membranes. Coin silver was selected because of its superior (compared to pure silver) mechanical properties, and because of the relatively modest heat capacity in a magnetic field. The membranes have a thickness of 0.5 mm. Ceramic piezo wafers were cut into disks and glued to the outside of the membranes using Stycast 1266 epoxy. To provide electrical contact with the piezoceramic, thin copper wires (0.125 mm in diameter) were attached using conducting silver epoxy. The length of the 97.5% aerogel (16.5 mm)

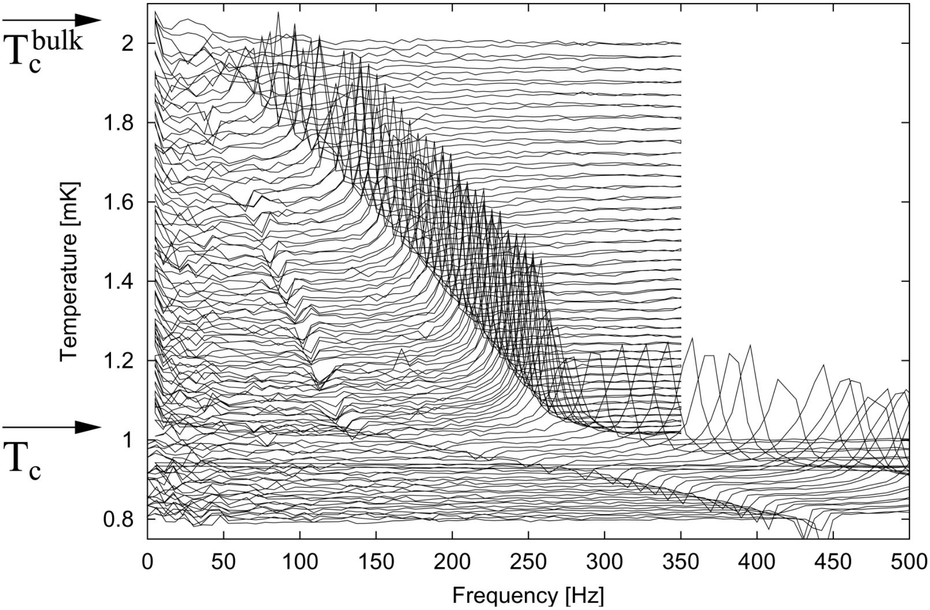

Fig. 2. Spectra of the quadrature response of the slow mode (P=14.89 bar, B = 76 mT) offset vertically with temperature. The smaller negative peak which shows a change in slope at T_c= 1.03 mK is the fundamental slow mode resonance. Above T_c the slow mode is converted into the slowly varying "edge" mode that disappears at $T_c{}^{bulk}$ = 2.064 mK. The larger positive peak is the Helmholtz resonance. The Helmoltz mode is sensitive to the superfluid transition in aerogel due to the strong coupling with the slow mode.

was machined so that the coin silver membranes were in contact with the sample when the cell was fully assembled. The lower part of the cell was made from polycarbonate plastic (Macrolone) which has a field independent specific heat. A vibrating wire thermometer was installed to monitor the temperature T inside the experimental volume. A melting curve thermometer was used to measure the temperature of the nuclear stage.

The measurements discussed in this paper were taken at a fixed pressure of P = 14.89 bar and the magnetic field B was varied between 10 mT and 800 mT. Fig. 2 is an example of the second sound like mode, the speed of which exceeds 10 m/s only at the lowest temperatures as calculated from the resonant frequency and cell length. Using the relation taken from A.Golov et al.[3]

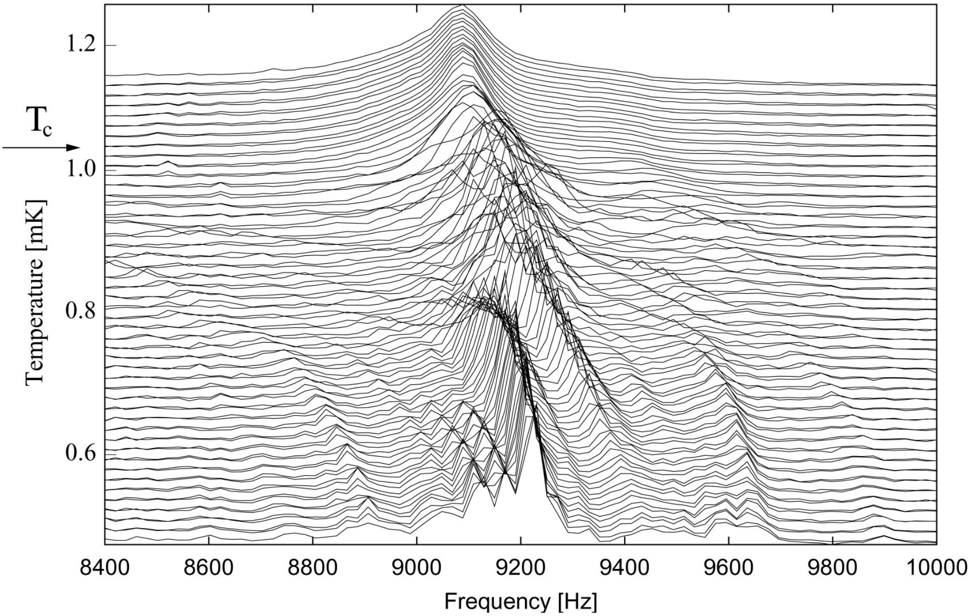

Fig. 3. CW spectrum of the fast mode at P = 14.89 bar and B = 100 mT.

$$\frac{\rho_s}{\rho} = \frac{\rho}{\rho_a}\left(\frac{c_s}{c_a}\right)^2, \tag{1}$$

where c_s and c_a are the speed of second sound in ^{3}He and the speed of sound in aerogel respectively the ρ_s/ρ can be determined from the measured ratio of sound velocities, c_s/c_a. Contrary to previous measurements[3], it has been found that the Helmholtz mode (which is a manifestation of bulk ^{3}He properties) is strongly coupled to the slow mode, as indicated by the change of slope occurring at T_c aerogel. This coupling may arise from the cell design—the bulk ^{3}He volume has approximately the same size as the experimental volume filled with aerogel. Furthermore, the aerogel sample is located between the sinter volume and the vibrating wire chamber which makes the behavior of ^{3}He confined to aerogel important for the Helmholtz resonance.

Fig. 3 plots the spectrum of the first sound like mode. It shows the CW signal versus frequency at a constant drive level. The sound velocity of the fast mode reaches 303 m/s at the lowest temperature. Below T_c= 1.03 mK the fast mode shifts towards higher frequencies which agrees with

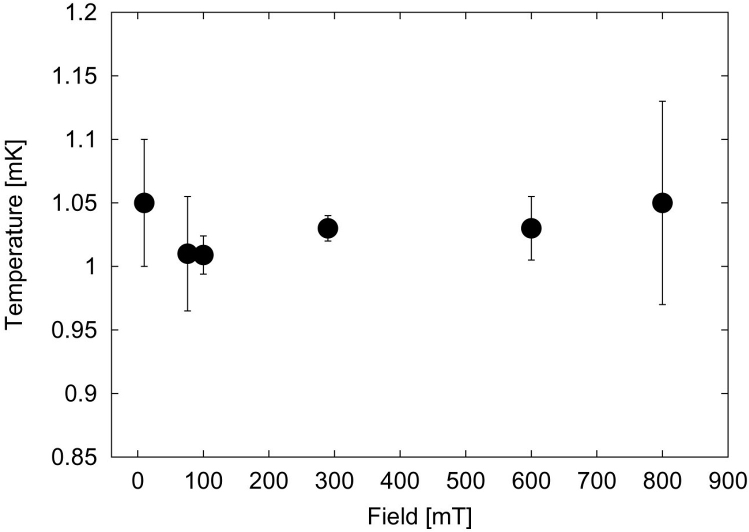

Fig. 4. Magnetic field dependence of the superfluid transition in ^{3}He in aerogel.

the behavior observed by A.Golov et al.[3]. This value for T_c is lower than previous measurements on less porous 98.2% samples[6]. As the temperature was decreased further we found that the fast mode was crossed by higher harmonics of the slow mode. This effect was observed at lower fields (below B = 300 mT) and vanished at B = 800 mT.

The magnetic field dependence of the superfluid transition of ^{3}He in aerogel is shown in Fig. 4. There is no significant suppression of T_c in aerogel by an applied magnetic field. This field independence is similar to bulk ^{3}He behavior, and disagrees with the previously reported B^2 dependence of T_c[7].

In conclusion, we have investigated two sound modes in ^{3}He in aerogel at various magnetic fields. The second sound like (slow) mode corresponds to thermal oscillations in ^{3}He in aerogel and exists only below T_c. The volume resonance (Helmholtz mode), which is a feature of bulk ^{3}He superfluidity, was also observed. The first sound-like (fast) mode which is a compression wave was seen in both normal- and superfluid state. Sound mode analysis shows no field dependence of T_c in aerogel. By continuing these experiments over a range of applied magnetic fields and pressures we hope to explore the P,T,H phase diagram of ^{3}He in aerogel.

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