Journal of Low Temperature Physics, Vol. 113, Nos. 3/4, 1998

Sound Modes of Superfluid ^{3}He in Aerogel

D.A. Geller, A. Golov, N. Mulders*, M.H.W. Chan†, and J.M. Parpia

LASSP, Cornell University, Ithaca, NY 14853-2501, USA
**Dept. of Physics, University of Delaware,*
Newark, DE 19716, USA
†Dept. of Physics, The Pennsylvania State University,
University Park, PA 16802, USA

We present the results of experiments on sound propagation at audio frequencies in ^{3}He-filled aerogel. Sound modes were observed at temperatures of 0.8–100 mK in an aerogel sample of 98% porosity. We find that below T_c for superfluid ^{3}He in the aerogel matrix the speed of sound in the composite system increases by as much as 1.5%. Also below the aerogel T_c new modes appear which correspond to propagation speeds of up to ~10 m/s.

PACS numbers: 67.57.-z, 67.57.De, 67.57.Hi, 67.57.Pq

1. INTRODUCTION

It has previously been shown by McKenna *et al.*[1] that superfluid ^{4}He can support two modes of sound propagation in high-porosity aerogels. The model they use to describe this composite system is an extension of two-fluid hydrodynamics in which the aerogel contributes to the density of the normal fluid and also contributes a restoring force. The speeds of sound of the two modes are solutions of the equation

$$\left(c^2 - c_1^2\right)\left(c^2 - c_2^2\right) + (\rho_a/\rho_n)\left(c^2 - c_a^2\right)\left(c^2 - c_4^2\right) = 0, \qquad (1)$$

where c_1, c_2, and c_4 are the speeds of first, second, and fourth sound, c_a is the speed of sound in the empty aerogel, and ρ_a is the mass density of the aerogel. The mode with the higher propagation speed is similar to first sound in the bulk fluid in that the normal and superfluid components of the helium oscillate in phase with one another, though not at the same velocity. Although the normal component of the helium is locked to the porous medium, as it would be in fourth sound, the aerogel itself is compliant so that the silica and fluid components can all move in phase with one another. The slower mode is similar to second sound in that the superfluid component moves out of phase with the normal fluid and the silica strands.

In the current experiment, we have found that ^{3}He in aerogel has qualitatively similar behavior to this model when cooled below its critical temperature at a pressure of 21.6 bar.

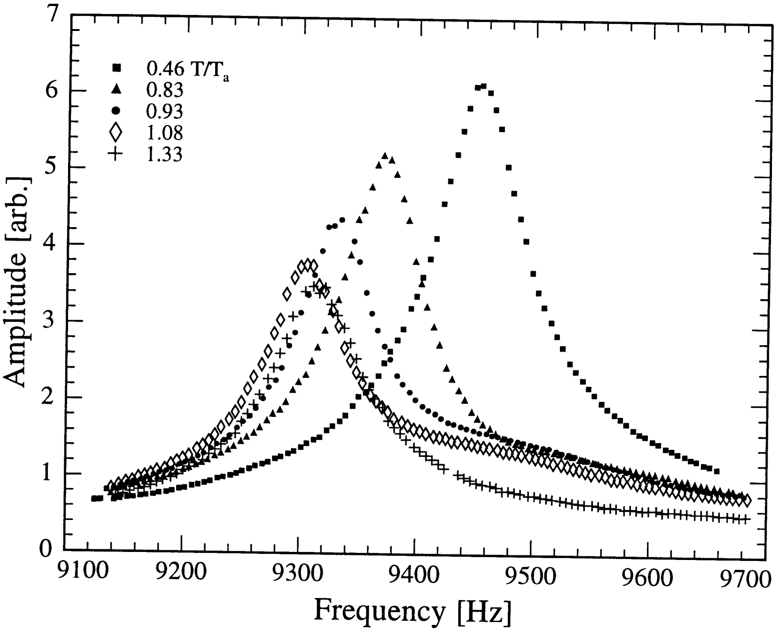

Fig. 1. CW spectrum of the fast mode at various reduced temperatures.

2. EXPERIMENTAL CELL

In previous acoustic experiments on ^{4}He in aerogel, other groups have used cells consisting of a heater and bolometer to measure the second-sound-like mode.[1,2] The cell used in these experiments, in contrast, employs thin, non-porous metal membranes to generate and detect both fast and slow modes of sound in the ^{3}He-aerogel system.

Our resonator consists of a cylidrical brass pressure cell with a brass flange at each end. The round metal membranes were plunge-cut into the exterior surface of the brass flanges. Ceramic piezo wafers were cut into disks and epoxied onto the membranes on either end, outside of the sample volume. The 98% porosity aerogel sample was grown into a round stainless steel sleeve about 1.6 cm long and 1 cm in diameter, and the ends were sanded to make the aerogel's open surfaces flush with the ends of the sleeve. The sleeve was then inserted into the brass pressure cell, in which a thick dab of silicone grease was applied to glue the sleeve against the brass surface at low temperatures.

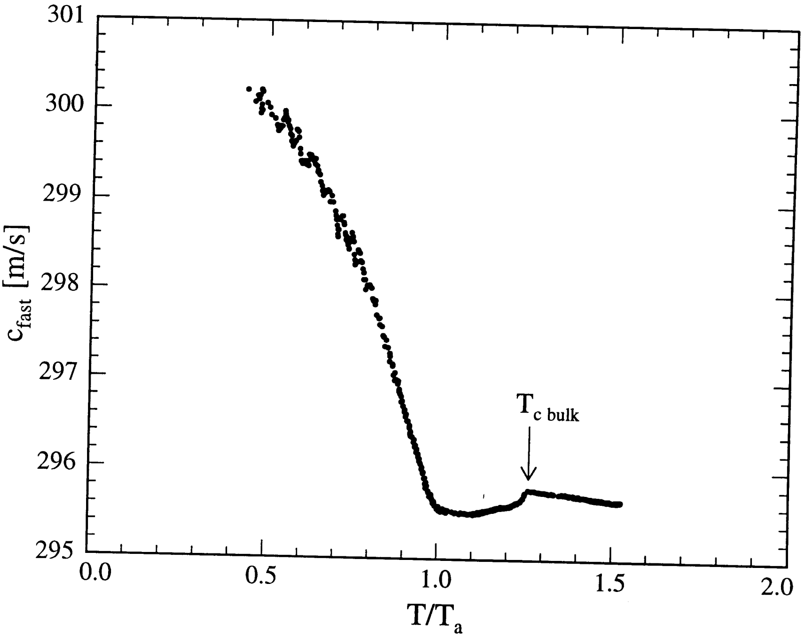

Fig. 2. Speed of the fast mode increases below T_a.

3. RESULTS

3.1. The Fast Mode

The data presented here are for ^{3}He at a pressure of 21.6 bar. Figure 1 shows received CW signal versus frequency for a constant drive level at several different temperatures. The signal-to-noise and quality factor of the resonances are sufficiently high to easily resolve the frequency shifts with temperature. In Figure 2, we plot the speed corresponding to the resonant frequency as a function of temperature. Above the bulk T_c for this pressure, the speed of sound is nearly constant. We are able to detect the bulk T_c by a small decrease of the speed of sound, which suggests that we have some bulk sound paths remaining in the cell around or through the aerogel plug. Below a critical temperature T_a the speed of sound abruptly begins to rise. This T_a is consistent with the supressed superfluid transition temperatures measured by torsional oscillators at the same pressure and aerogel porosity. The speed of sound reaches a value about 1.5% percent higher than in the normal liquid at the lowest temperatures, which is in qualitative agreement with equation (1). The noise in the data of Figure 2 at the lowest temperatures is due to the presence of high harmonics of the slow mode which appear and cross the fundamental of the fast mode well below T_a.

3.2. The Slow Mode

Below T_a we observe a new propagating mode, the speed of which exceeds 10 m/s only at the lowest temperatures reached. Overlayed spectra at several temperatures are shown in Figure 3. The speed of this slow mode drops rapidly as the cell warms toward T_a. Close to T_a the amplitude of the resonance also rapidly decreases. Figure 4 shows the speed of the slow mode as a function of temperature for two sweeps at different drive levels. The dense data close to the bulk and aerogel transition temperatures were taken with 10 times higher drive level, which seems to cause slight heating of the sample. The slow mode does not completely vanish until bulk T_c, but the speed of sound decreases very slowly from T_a until very close to T_c. This has also been observed (but was not well resolved) before for ^{4}He in aerogel by Mulders *et al.*[2]

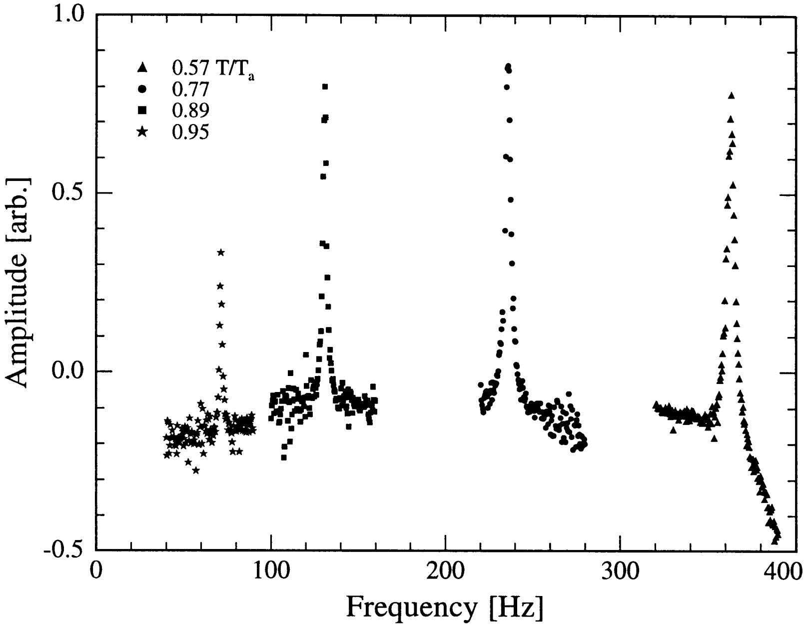

Fig. 3. Spectrum of the slow mode at various reduced temperatures.

4. CONCLUSION

We have observed two distinct modes of sound propagation in ^{3}He-filled aerogel. These modes resemble the first- and second-sound-like modes seen in ^{4}He in aerogel. Although we believe the frequency shift of the fast mode and the existence of the slow mode depend on a superfluid transition in the ^{3}He, we find no dependence of either mode on transverse magnetic fields up to 30 Gauss.

ACKNOWLEDGMENTS

This research was supported by NSF under DMR 94-24131, DMR 97-05295, and DMR 97-01710.

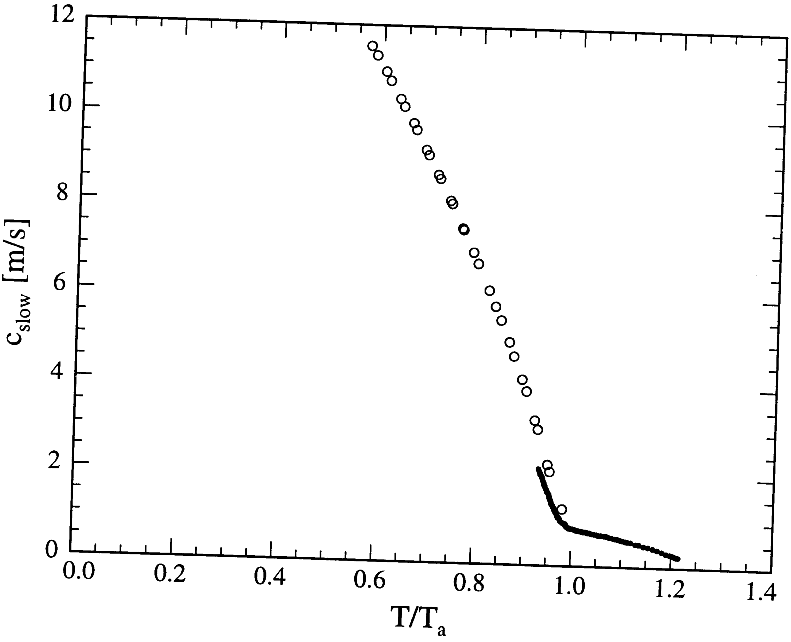

Fig. 4. Speed of the slow sound mode as a function of reduced temperature.

REFERENCES

1. M.J. McKenna, Tania Salwecki, and J.D. Maynard, *Phys. Rev. Lett.* **66**, 1878 (1991).
2. Norbert Mulders, Ravi Mehrotra, Lori S. Goldner, and Guenter Ahlers, *Phys. Rev. Lett.* **67**, 695 (1991).