Acoustic Properties of 97% Porous Aerogel at Low Temperatures

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Abstract

Sound transmission techniques were used to investigate sound velocities and attenuation in an aerogel sample of 3 mm length and 3 mm diameter. This sample was squeezed between a 10 MHz transmitter and receiver quartz. Pulsed measurements were performed during several cool down cycles (300 K to 0.7 K) in vacuum as well as while filling the aerogel with gaseous and liquid ^{3}He up to 29 bar. The striking features of all experiments were that a profound change of the sound mode in the ^{3}He-filled aerogel occurs around 5, 8 and 12 bar, and that neither sound velocity nor absorption in the aerogel has been found very reproducible from cool-down to cool-down.

Key words: sound-transmission; porous media; Fermi liquid ^{3}He

During the past few years superfluid ^{3}He immersed in highly porous aerogel gained growing interest [1] because this system allows to study superfluid properties under the influence of the disorder introduced by the silica strands of the aerogel. All experiments on ^{3}He in aerogel show sharp transitions into the superfluid phase and hence show convincingly that there is a homogeneous superfluid. The common experimental finding is an increasing suppression of the transition temperature and of the superfluid density with decreasing porosity of the aerogel and ^{3}He pressure. There is one experimental exception to that where such a suppression has not been observed [2]. In these pulsed ultrasonic experiments ^{3}He was immersed in a commercially available aerogel of 97% porosity [3]. In order to understand whether specific properties of differently produced aerogels were influencing T_c-shifts, we investigated aerogel at low temperatures by acoustic methods.

Sound transmission techniques were applied to investigate the acoustic response of the aerogel to a usually 4 μs wide 10.03 MHz pulse of ∼90 V amplitude. Overtone polished matched pairs of quartzes (ringing time 5μs) were used. The received signal was monitored by a cold preamplifier after the sound-pulse was traveling through the 3 mm long sample of 3 mm diameter. In addition, digital filtering techniques had to be applied to improve the S/N-ratio of the very weak signals received from the aerogel sample in the vacuum [4]. Before a cool down cycle, the ^{3}He-cell was flushed many times with ^{3}He-gas and finally evacuated to a pressure of better than 0.1 mbar. The ^{3}He-cell was coupled to the cooling stage by a heat-exchanger made of 70 nm sized Ag-powder. The surface area of this exchanger was more than ten times bigger than the ∼1 m^2 surface on the SiO_2-strands of the aerogel. Therefore we believe that cryopumping due to the action of the heat exchanger (which becomes cold first) will keep the aerogel clean from residual gas condensation while cooling. The pressure in the cell was monitored by a capacitive gauge located on the entrance of the ^{3}He-filling capillary to the cell.

The main interest of our investigation was to characterize the high frequency oscillation modes of the aerogel and how these modes vary if temperature is changed (fig. 1). It was also of interest whether or not these modes and their sound velocities are changed from cool down to cool down (fig. 1) [5], and whether the acoustic behavior is the same while compressing and decom-

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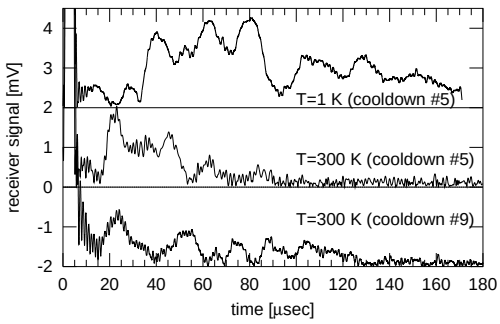

Fig. 1. Received signals after a 4 μs-excitation was traveling through aerogel in vacuum. Time starts with the beginning of the pulse (visible at the beginning is the electrical cross-talk of the pulse). Spectra are shifted for clarity. The top two traces show spectra at different temperatures of one cool-down. The lower two traces show spectra at 300 K taken in two different cool-downs.

pressing the cell with ^{3}He (fig. 2).

From fig. 1 it is obvious that the sound velocity c_1 [6] in an aerogel depends on temperature T and on history. c_1 at 1 K is about two times lower than c_1 at room temperature. This indicates that the stiffness of the aerogel has to become weaker at low T and/or that the density rises with decreasing T. From fig. 1 it becomes also clear that the complex aerogel structure widens the emitted pulse by more than a factor three. The threefold structure in the received signal does not reflect the exponentially shaped pulse which is radiated by the quartz. Since our ^{3}He-cell was not opened for years and since room temperature spectra are not reproducible from cool-down to cool-down we have to conclude that irreversible changes take place in the aerogel if the sample is exposed to thermal stress.

History-dependent effects are also present when the aerogel is loaded with ^{3}He. The pressure dependence of the sound modes in the ^{3}He-aerogel system is complicated as shown in fig. 2. Whether the abrupt changes in the sound spectra at certain pressures are related to a rearrangement of the solid ^{3}He-layers on the aerogel-strands or whether these changes are caused by changes in the aerogel structure is unclear. However, from fig. 2 it becomes clear that these changes are irreversible at least during one cool-down cycle. This brings us to the conclusion that aerogels are not very well defined systems if their macroscopic structure is considered.

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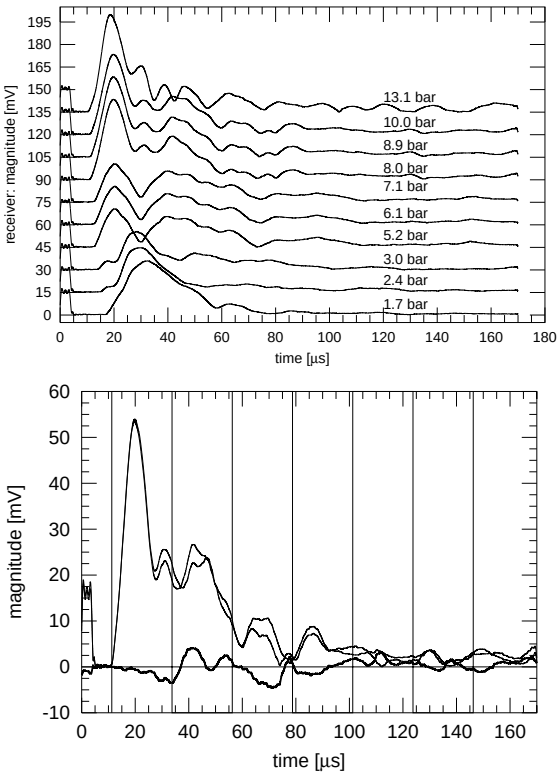

Fig. 2. Sound spectra of ^{3}He filled aerogel at 1 K. The first arriving signal corresponds to the in phase oscillating ^{3}He-aerogel system (fast mode). Top: First compression. Note the pressure-dependent build-up of the fast mode, sound velocity changes as well as amplitude. Note also the structural changes at pressures around 5, 8 and 12 bar. Bottom: First decompression. Spectra were taken at 8.8 bar during pressure-sweeps up and down. The difference of these two signals is also shown. Note the history dependence of the signals for $t \geq 30$ μs. Markers indicate a fast mode propagation (reflexions) with c_1=267 m/s.

References

[1] see e.g. P. Brussaard et al., Phys. Rev. Lett. **86** (2001) 4580 or G. Gervais et al., arXiv:cond-mat/0202323 v 1 (2002) and refs. there.

[2] L. Hristakos, PhD-thesis, Universität Bayreuth (2001).

[3] from Matsushita Electric Works Ltd., Osaka, Japan; characterized by: porosity α=97%, density ρ=0.067 g/cm^3 and surface to weight ratio σ_{ae}=515 m^2/g.

[4] Acoustic mismatch is expected since impedance matching is hard to achieve in a ^{3}He-aerogel system (best in a narrow range of Helium pressures $\sim$15 bar and aerogel porosity $\sim$92.5%).

[5] Irreproducibility is expected due to thermal and acoustic stress which leads to uncontrolled break of some of the brittle SiO_2-strands.

[6] in our set-up c_1=0.003 m/(time of first rise in the signal) leading to c_1 $\sim$100-200 m/s for aerogel in vacuum.