Observation of Superfluidity of ^{3}He in Aerogel by 4th Sound Technique

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Abstract

The superfluid transition temperature and superfluid density of superfluid ^{3}He in aerogel are revealed to be largely suppressed with respect to those of bulk liquid. We have studied superfluidity of ^{3}He in aerogel of nominal porosity of 98.5%, 98.0%, and 97.5% by fourth sound technique. The superfluid transition temperature $T_C^{\rm aero}$ has been recognised by sharp change of quality factor of resonating sound. $T_C^{\rm aero}$ was suppressed as previous experiments. Unexpectedly we observed the signal from the fourth sound resonator between $T_C^{\rm aero}$ and bulk T_C. The loss of fourth sound was independent of temperature at the lowest temperature. Such a behaviour is quite different from previous fourth sound experiments without aerogel.

Key words: superfluid ^{3}He ; aerogel; fourth sound; viscous mean free path

The superfluidity of liquid ^{3}He in aerogel is interesting because the silica strands, the distance between which is widely distributed from 1 to 100 nm, do not destroy the superfluidity completely but suppress the transition temperature T_C and the superfluid density ρ_s. In previous experiments even with the same porosity in aerogel the transition temperatures differed for cell by cell. This indicated that the internal structure was important, whose structural details might be different due to growth condition.

To study the superfluidity of liquid ^{3}He in aerogel, fourth sound experiments were performed. We have prepared three different aerogel cells with porosity of 98.5%, 98.0%, and 97.5%, which were made by Yokogawa and Yokoyama in Matsushita Electric Works Ltd. These aerogels have an advantage having no secular change with little difference in structural details. First, in empty sound resonators we sintered almost spherical silver powder, whose diameter was around 70 μm , with a packing factor of 60%. These resonators were soaked in "methyl silicate solution" to grow aerogel directly in a gap among sintered silver powders. An average gap was estimated to be around 5 μm in radius. Such a sintered silver sponge will function as a wall to clamp a normal fluid component in superfluid ^{3}He. We also expect it as a wall to clamp aerogel, which means that silver powder prevents aerogel strands from moving in sound experiments. This expectation was verified in superfluid ^{4}He, where the fourth sound velocities corresponded with the calculated ones in bulk liquid with the acoustic refraction index. We had the empty cell that has nothing inside to measure the first sound velocity. At both ends of sound resonators, we attached a piezo-electrode as a pressure transducer to drive and detect a resonating sound. The first sound velocity C_1, superfluid density ρ_s and total density ρ gives the fourth sound velocity C_4 as follows;

$$C_4^2 = \frac{\rho_s}{\rho} C_1^2. \tag{1}$$

By measuring C_4 and C_1, the superfluid density can be

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obtained by using Eq.(1). Besides, the quality factor of a sound is measured which includes the information about the viscosity and the mean free path. Here we report only the experimental results in 98.5% aerogel at 13 bar, where T_C in bulk liquid is 1.98 mK.

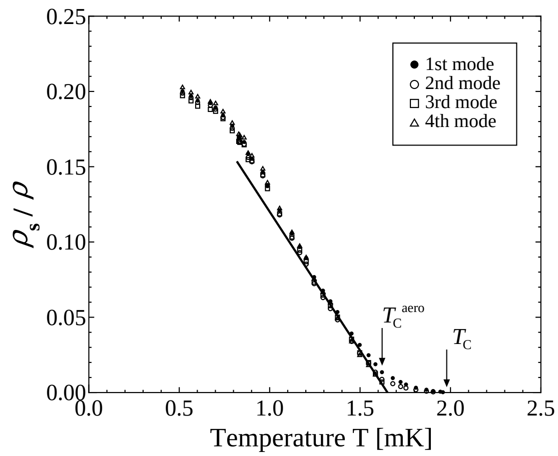

Fig. 1. ρ_s/ρ as a function of temperature in 98.5% at 13 bar. Solid straight line shows the linear temperature dependence near $T_C^{\rm aero}$.

In Fig.1, we plotted the superfluid density as a function of temperature, where we observed four resonance modes at low temperatures as a fourth sound. All modes give almost the same ρ_s/ρ which was, however, largely suppressed from the bulk value in all temperatures. But near bulk T_C two low frequency modes were still observed. The transition temperature in aerogel was often determined by supposing the linear temperature dependence in ρ_s near transition, which was around 1.65 mK. In Fig.2 we plotted the inverse of quality factor of resonating sound as a function of temperature. Around 1.65 mK there is a sharp drop in

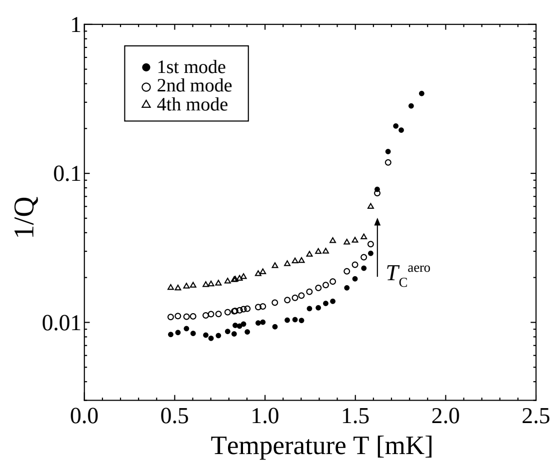

Fig. 2. Q^{-1} as a function of temperature in 98.5 % aerogel at 13 bar.

Q^{-1} of 1st and 2nd mode. At lower temperature Q^{-1} gradually decreased and almost constant at the lowest temperatures. From these features we conclude that $T_C^{\rm aero}$=1.65 mK and at lower temperatures a fourth sound with a small loss was detected with growing the superfluid density in aerogel. It is interesting that there was a sound mode that was related to superfluidity of bulk liquid between T_C and $T_C^{\rm aero}$. Such a phenomenon was observed in Ref.[1] which suggested a possibility of new phase of superfluid ^{3}He .

In a hydrodynamic treatment the loss of fourth sound was calculated with a slip approximation,

$$Q^{-1} = \frac{\rho_n}{\rho_s}\frac{\langle R\rangle^2}{4\delta_v^2}\left(1+\frac{4\zeta}{\langle R\rangle}\right), \tag{2}$$

where ρ_n is the normal fluid density and $\langle R\rangle$ is an average pore radius in sintered silver and δ_v is the viscous penetration depth and ζ is a slip length[2]. Here we assume that a slip length is the same order of viscous mean free path as in bulk liquid[3]. Because of ^{3}He confinement in aerogel, we presume the mean free path should be so shorter than that of bulk liquid of 10 μm at least that we can neglect the second term in the right hand side in Eq.(2). The calculated δ_v shows a rapid decrease below $T_C^{\rm aero}$ and nearly constant at the lowest temperatures. This behaviour is quite different from that in bulk liquid where δ_v increases toward $T = 0$ due to a rapidly decreasing normal fluid density[3]. Since δ_v is defined as $\sqrt{2\eta/\rho_n\omega_4}$, where ω_4 is the fourth sound angular frequency, we can calculate the shear viscosity $\eta^{\rm aero}$ in aerogel. It should be noted that $\eta^{\rm aero}(T)/\eta_C$ is about a half of those of bulk liquid and almost constant at the lowest temperature; η_C is the shear viscosity in bulk liquid at T_C. The shear viscosity, in general, is given as a product of ρ_n, the averaged quasiparticle group velocity $\bar{v}(T)$ and the viscous mean free path. The velocity $\bar{v}(T)$ is expected to be a slowly varying function at low temperatures. Because of the large ρ_n and slowly varying $\bar{v}(T)$, $\eta^{\rm aero}(T)/\eta_C$ suggests the mean free path is very short and shows no strong divergence toward $T = 0$. These are consistent with the above assumption that the mean free path in aerogel is suppressed by silica strands.

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