Torsional Oscillator Experiment for Superfluid ^{4}He in porous glass well below 1K under rotation

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Abstract

3D features of the superfluid ^{4}He film as well as the bulk superfluid ^{4}He in a porous glass are being studied with the Tortional Oscillator technique to examine the effect of rotation. We have completed an experimantal set-up which enables us to study the Torsional Oscillator under rotation up to 4 Hz at dilution refrigerator temperatures. For comparison with classical persistent current experiments, we started the direct measurement of the bulk superfluid density well below 1K and we have observed the T^4 phonon contribution to the normal conponent.

Key words: superfluidity ; persistent current ; vortex ; pore vortex

1. Introduction

Superfluid ^{4}He in the restricted geometries like porous media has been providing an ideal condition for superfluid studies. The wall of a porous substrate drags the normal conponent and there is left the only superfluid conponents. In practice, the normal component is almost entirely bound on the surface, which has a benefit for the experimentalists in allowing a high resolution measurement. Porous media is famous for persistent current experiments [2,5]. Unfortunately, these experiments were done just above 1K bacause their cryostats are often 1K cryostats. The temperature restriction didn't allow the entire understanding of the interior physics related to a persistent current.

Porous media has also been used for superfluid ^{4}He film experiments. It is well known that the ^{4}He submonolayer film undergoes a superfluid transition and that the ^{4}He film experiments on porous media also show some 3D behavior [6,8]. These 3D properties are thought to be caused by the multi-connectivity of a porous media. Because it is not always a good strategy to compare the 3D system made of the locally thin film with the homogenious 3D system in a direct way, some theoretical efforts have also been done [7,9]. We have been doing the experimental efforts in order to

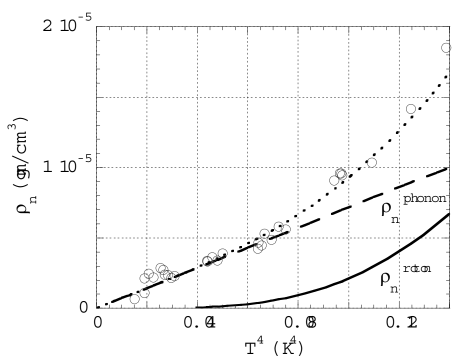

Fig. 1. T^4 vs. normal component contribution well below 600 mK. The circles are the normal component density. The solid line is the fitting by roton contribution and the broken line by phonon contribution. The dotted line is the sum of both. On this graph, the T^4 dependent phonon contribution is seen below 500mK.

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understand the 3D properties from the aspect of the rotation induced pore vortices.

From these motivations, we are developing the Torsional Oscillator with a porous glass substrate of 1 μm pore size on the rotational dilution refregiator up to 4 Hz. For the moment, we measured directly the superfluid density of the full pore superfluid ^{4}He in the porous glass well below 1K as a direct measurement of the super fluid density. This measurement tells us that phonons are the dominant contribution to normal component well below 0.6K.

2. ^{4}He superfluid density in porous media well below 1K measured by the Torsional Oscillator technique.

Our experiment is well-known Torsional Oscillator. The resonant frequency or period is shifted by the reduction of the moment of inatia of the normal fluid. The amount of a period shift is related the the normal component density as following.

$$\rho_n(T) = \frac{\rho}{(1-\chi)}\left[\frac{P(T)-P(0)}{P(T_\lambda)-P_0}\right],$$

where ρ is the liquid density just above T_λ, χ is tortuosity factor, P_0 is the empty cell period, and $P(T)$ the period at temperature T. Inside of the cell some superfluid components flows along the direction of the TO vibration, and others flows across the direction of the TO vibration. The first is measured as a superfluidity but the second resists the vibration, namely the TO measures superfluid component like normal component. The χ factor complements such kind of the over estimation. We measured the superfluid ^{4}He density in a porous glass with the pore diameter of 1 μ m from above T$_\lambda$ down to a few hundreds mK. The experiment data is shown in Figure 1. The measurement is done using a dilution refregiratior and the measurement could be taken well below 1K [10].

In Figure 1, the normal component estimated from the period shift is shown as well as the two estimated contributors to a normal fluid density due to phonon and roton excitations. The solid line is a roton contribution, the dashed line a T^4 phonon contribution, and the dotted line is the sum of both. In the figure, the horizontal axis is T to the powers of 4 and the vertical axis is the density of normal component. The total amounts of them are fixed with the fitting coefficients;

$$\rho_n^{phonon} = 7.16\times10^{-5}T^4 \quad (gm/cm^3)$$
$$\rho_n^{roton} = 4.57\frac{\exp(-8.36/T)}{\sqrt{T}} \quad (gm/cm^3)$$

The fitting is done for phonon and roton below 560mK and 1.5K respectively. We could estimate the first sound velocity from the slope of the broken line. The estimation is 180 (m/s) and this value is slightly smaller than the one typically reported - 236 (m/s). In Ref. [3], the sound velocity in a restricted geometry is slightly refracted by the structure. The refracted phonon velocity in the restricted geometry is extimated as $\tilde{U_1} = U_1\cdot\sqrt{1-\chi}$. The χ factor is 0.526 and the refracted sound velocity matches our fitting parameter within 12 % error.

Phonon contribution and roton contribution cross around T = 650mK and the only phonon contributes to normal component in the lower temperature region. Actually there is left only the phonon contribution below $T^4 = 0.1(K^4)$ in the graph.

We should note the viscous penetration depth to make sure we don't over/under estimate from our graph. for As concerned with a viscosity just above T$_\lambda$ [4], we calculated the period modification due to a viscosity. The ratio h/δ of the pore size, h, and the viscous penetration depth, δ is 0.533 and the viscous penetration depth is slightly longer. This means the fluid is not completely locked to the porous medium and we should estimate the superfluid density more carefully. The formulae are shown in Ref. [4] and the actual complementation is just 0.1 % of the total mass of superfluidity while the Q value is 66 times smaller than that of the empty cell.

With our experimental set up, we are now considering a measurement of the reduction of superfluid density due to the persistent current existance. It has been a long time since this subject had been studied, and the earlier measurements were restricted to temperatures well above 1K. With our millikelvin rotating cryostat we hope to contribute to the understanding of this problem.

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