In Globally Isotropic Aerogel, A-B Phase Separation of Superfluid $^3$He in Radial Direction

Ryusuke Kado, Hisashi Nakagawa, Ken Obara, Hideo Yano, Osamu Ishikawa and Tohru Hata

Graduate School of Science, Osaka City University, Osaka, 558-8585, Japan
National Metrology Institute of Japan, National Institute of AIST, Tsukuba, 305-8563, Japan
E-mail: kadoryu@sci.osaka-cu.ac.jp

Abstract. It is observed that the A-like phase and the B-like phase, which are superfluid phases of $^3$He in high porosity silica aerogel as an impurity, coexist stably [1]. In this coexisting state, we showed by NMR experiments with radial gradient magnetic field that the A-like phase is in the edge part of a cylindrical aerogel and the B-like phase is in the central part of that [2]. It is proposed that the A-like phase might be more stabilized in globally anisotropic aerogel. According to this proportion, the aerogel might be globally anisotropic in edge part. In order to study whether the aerogel is globally anisotropic, we have performed optical birefringence experiment on aerogel samples in the same batch. This optical method is a useful tool to characterize a global anisotropy of aerogel [3]. Then, we found that aerogel samples are not globally anisotropic. Therefore, there are another mechanism for the A-B phase separation in radial direction.

1. Introduction

Superfluid $^3$He in the aerogel provides a system for study of impurity scattering effects on p-wave superfluid. The aerogels consist of a dilute network of silica strands. They have typically an open volume of 98%. The strands are a few nanometers in diameter and the average interstrand distance is a few tens nanometers. The coherence length of superfluid $^3$He, $\xi_0$, which varies from 65 nm at zero pressure to 13 nm at the melting pressure, is larger than the strand diameter but is comparable to the interstrand distance. Because of this, the aerogel act as an impurity for superfluid $^3$He.

We have studied the superfluid phases of $^3$He in 97.5% porosity cylindrical aerogel by NMR method. It has been observed that the superfluid transition temperature is suppressed, and that suppression strongly depends on pressures [4]. Two different phases is observed and have been identified as the A-like phase and the B-like phase. The former is in equal spin pairing state near $T_a$ and the latter is in non equal spin pairing state at lower temperatures. The A-B phase conversion accompanies a phase boundary because of the first order phase transition. Both phases coexist within about 90 $\mu$K, where the A-like phase is in the supercooling state. When you keep the temperature constant in which both phases coexist, the A-B phase conversion stops. On the other hand, a steady coexisting state in bulk liquid has not been observed. By applying a field gradient which changes as a function of square of radius, we found that the A-like phase is in the edge part with a cylindrical shape and the B-like phase is in the central part with a columnar shape.
Recently, it has been suggested that anisotropic quasiparticle scattering will stabilize anisotropic phases of superfluid $^3$He. And it has been demonstrated that the global anisotropy of aerogel has a strong effect on the orientation of the orbital momentum. The cause of the observed coexistence state might be a global anisotropy of aerogel. In order to study whether the aerogel is globally anisotropic, we have performed optical birefringence experiment on aerogel samples in the same batch.

2. Experiments
The optical birefringence experiment is a useful tool to characterize a global anisotropy of aerogel. When a transparent material possesses an anisotropic dielectric constant it will exhibit birefringence. When white light enters an anisotropic material, it decomposes into two orthogonal polarized components, parallel and perpendicular to the "optical axis". By placing such a material between two polarizers whose polarization directions are perpendicular to each other, it is possible to determine if there is a well defined optical axis and how it is distributed throughout the sample. Measurements of optical birefringence are well-known for characterization of liquid crystals and many other materials.

The block diagram is shown in figure 1. A cylindrical aerogel sample in glass tube was placed between two crossed polarizers and illuminated with diffuse white light (halogen lamp). The cylinder axis was oriented parallel with a ray of light. A diffuser was placed between the light source and the first polarizer. Images were recorded with a digital camera located after the second polarizer. If the optical axis is parallel to the cylinder axis, or aerogel is globally isotropic, aerogel does not polarize transmitted light and light can not be observed.

Figure 1. The block diagram of the optical birefringence experiment. Light source is a halogen lamp. Light passes through a diffuser, the first polarizer (B), a aerogel sample and the second polarizer (A). Both polarizers are in the crossed position.

3. Results and Discussion
Figure 2 shows optical birefringence of 97.5% porosity aerogel in glass tube. It is assumed an angle of 0 degree that a polarization direction of the polarizer is a horizontal. This angle increases in the counterclockwise direction. In panel 1 of figure 2, the first polarizer and the second polarizer is oriented with an angle of 45 degree and 135 degree, respectively. The two polarizers rotates by 15 degree in the clockwise direction, keeping them crossed. In panel 7 of figure 2, both polarizer is oriented with an angle of 135 degree and 225 degree, respectively.

At the part of upper right of aerogel, light is transmitted depending on the angle of the polarizers. This indicates that this aerogel possesses locally anisotropic. At the edge part of aerogel, light reflected by glass tube is transmitted. These features are observed at 97.5% porosity aerogel in the same batch. The cylinder axis was oriented vertical, and we have also performed that experiments. Light was hardly transmitted. However, we note that aerogels are in the glass tube.

Therefore, 97.5% porosity aerogel in glass tube is globally isotropic, but locally anisotropic.
Figure 2. The optical birefringence of a 97.5% aerogel. The labels are associated with the rotation of the polarizers relative to the cylinder axis: 1 (45, 135), 2 (60, 150), 3 (75, 165), 4 (90, 180), 5 (105, 195), 6 (120, 210), 7 (135, 225). A broken line circle indicates the part of local anisotropy.

4. Conclusion
We observed the coexisting with the A-like phase and the B-like phase of superfluid $^3$He in the 97.5% porosity aerogel on cooling. In this coexisting state, we showed by NMR experiments with radial gradient magnetic field that the A-like phase is in the edge part of a cylindrical aerogel and the B-like phase is in the central part of that. According to the proportion that anisotropic quasiparticle scattering will stabilize the A-like phase, the aerogel might be globally anisotropic in edge part and isotropic in central part. We have performed optical birefringence experiment on aerogel samples in the same batch. Then, we found that aerogel samples are not such a globally anisotropic.

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