Anomalous Magnetic-Field Dependence of Positive Ion Mobility in Superfluid ^{3}He

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Abstract

Magnetic field dependence of positive ion mobility in liquid ^{3}He has been studied for the superfluid A_1 and A_2 phase. It exhibits an anomalous behavior, which is sensitive to the liquid pressure especially above 20 bar. The behavior is similar to that observed recently in the normal phase at 3.2 mK. This fact indicates that there exists a similar magnetic scattering mechanism between the positive ion and the ^{3}He quasiparticles in the superfluid phase.

Key words: superfluid ^{3}He; ion mobility

The ion in liquid ^{3}He is a heavy charged particle with a size of 1 nm at largest. It has been used for a long time as a sensitive and non-disturbing probe not only for investigating the elementary excitations but also for understanding the properties of the heavy charged particle in the Fermi liquid [1,2].

A positive ion forms a so called "snowball" where the ^{3}He atoms are attracted to the charged core ($^3He_2^+$) by its large local electric field. A recent measurement for the positive ion mobility revealed a pressure dependent anomalous magnetic field dependence at temperatures just above the superfluid transition [3]. Although the mechanism causing the behavior is not yet clear, a possible important role of Kondo-like exchange spin scattering of ^{3}He quasiparticles with the localized ^{3}He spins on the ion surface has been pointed out based on Èdel'shteĭn's proposal [4]. If so, how does the superfluid transition affect the behavior? In this report, we present high field measurements (< 15 T) in the superfluid A_1 and A_2 phase to have a complete understanding of the above phenomenon.

The experimental setup is the same as that in our previous work [3,5]. The magnetic field is in parallel with the ion velocity. In this geometry, the $\underline{l}$ vector in the A phase lies in the perpendicular plane to the ion velocity, and then the observed mobility is maximum in the A phase. The drift velocity was measured with a standard gated time-of-flight technique. The mobility is determined from a linear region in the velocity (v) vs. the driving electric field (E) relation. The high pressure samples above 29 bar were prepared by use of a capillary block method. To obtain a precise magnetic field dependence, the sample temperature was carefully controlled with a ^{3}He melting curve thermometer each time after the field sweep.

Fig. 1(a) gives the magnetic field dependence of the inversed mobility $1/\mu(H)$ in the A_2 phase for various pressures at constant temperature. The vertical axis is normalized by the value at zero field. Here we employ the value at 0.6 T as $\mu(0)$ and each data set is shifted for visual clarity. The behavior in the A_2 phase is quite similar to that in the normal phase at 3.2 mK as is shown in Fig. 1(b) [3]. In the A_2 phase, $\mu(0)/\mu(H)$ shows a larger increase in the high field region, and a small dip is much clearer than in the normal phase. On the contrary the behavior in the A_1 phase is different from in the A_2 phase as shown in Fig. 2(a). To get

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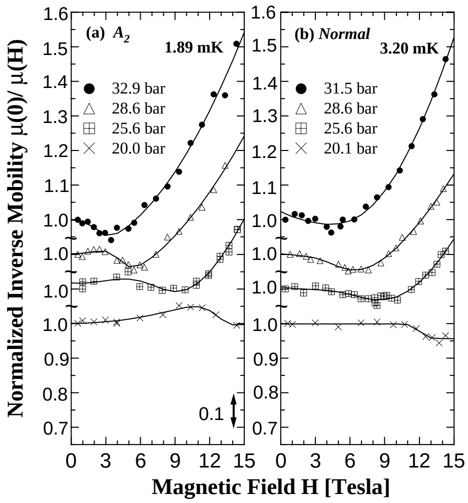

Fig. 1. The inversed mobility as a function of magnetic field under various pressures. (a) at 1.89 mK in the superfluid A_2 phase; (b) at 3.2 mK in the normal state. Vertical axis is normalized at 0.6 T.

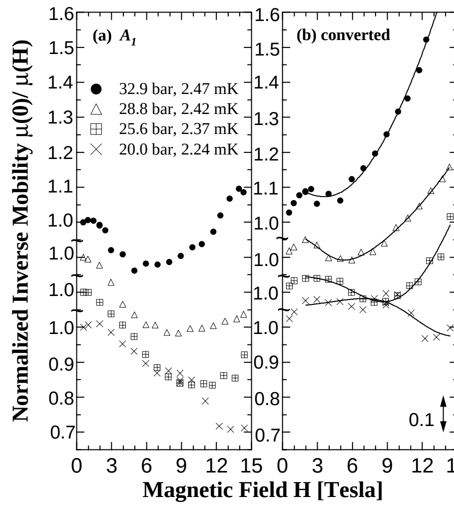

Fig. 2. (a) Field dependence of the inversed mobility in the superfluid A_1 phase under various pressures at T=T_c; (b) The converted field dependence (see the text). The symbols are the same in both figures. The Vertical axis is normalized by the value at 0.6 T.

the field dependence over the entire A_1 phase region, the temperature was kept at the zero field transition temperature (T_c) for each pressure. Thus the order parameter varies with magnetic field because of the field dependence of T_{A_1}. The change of the order parameter affects on the number of the quasiparticles as well as on the transport cross section. This change can be taken into account by use of a field-independent universal function, which gives a rough indication for the change of the number of the quasiparticles [6]. The converted field dependence is shown in Fig. 2(b). The above estimation is very crude, but the obtained feature turns out to be similar to the normal and the A_2 phase, except in the low field region below 2 T.

As shown in Fig. 1 and 2(b), the effect of the pressure on the field dependence is very similar among the three phases. The higher the pressure, the field dependence becomes stronger and the dip in $\mu(0)/\mu(H)$ moves to the lower field. The field dependence is very complicated, but seems to have a common feature that there exist two contributions . The first one gives a gradual increase, which is enhanced at high pressures. From the analysis in the high fields at high pressures, the field dependence is found to be proportional to $\sim H^2$. The other brings a relatively sharp dip only seen at low temperature which strongly depends on the pressure [3]. Since there exists no theory for the positive ion mobility under such high magnetic fields, we tentatively fit the data using the experimental formula which is a product of a quadrically increaasing term and a step-like term for the dip. The fitted curves are given in Fig. 1 and 2(b) as the solid lines, which reproduce the observed dependence surprisingly well in the whole pressure region.

In summary, the positive ion mobility has been measured in the superfluid A_1 and A_2 phase, under high magnetic fields at various pressures. The magnetic field dependence at high pressures exhibits a peculiar behavior which is similar to the normal phase. This indicates that the magnetic scattering between the ion and the quasiparticles play an important role even in the superfluid phase. The theory which depicts the microscopic feature of the magnetic scattering is highly desired.

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