Spin Diffusion in Normalfluid ^{3}He in 97% Porous Silica-Aerogel

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Abstract

Spin relaxation and spin diffusion were investigated in a liquid ^{3}He sample in contact with solid ^{3}He which was adsorbed on the SiO_2 strands of an aerogel. NMR experiments at 950 kHz were performed at pressures and temperatures ranging from 0-20 bar and from 0.2 to 100 mK, respectively. The results for the diffusion coefficient D_0 are not only affected by the effective mean free path in the aerogel but also by the solid-layer magnetization. For T<3 mK a diffusion coefficient $D_0 \sim$T has been observed which is caused by scattering processes associated with the spin-polarization of adsorbed solid ^{3}He-layers.

Key words: spin-scattering; spin-polarization; spin-diffusion; Fermi liquid ^{3}He

Superfluid Helium immersed in aerogel has been intensively studied during the last few years, only little was done on the Fermi liquid ^{3}He in contact with aerogel. This was in part because the pressure (p) dependent quasiparticle (qp) scattering rate ($\tau_{qp}^{-1} = T^2/\tau_0$) was expected to become dominated by qp-scattering on the aerogel strands at a rate $\tau_{ae}^{-1} = v_F/\lambda$ with λ being the geometrical mean free path of the aerogel. These two rates are equal at $T_x = (\frac{\tau_0 v_F}{\lambda})^{0.5}$ ~15 mK, e.g. for 0 bar and an aerogel of 97% porosity (λ ~100 nm). For $T \ll T_x$ spin-diffusion (D_0) is expected to become T-independent. In this paper we present NMR-results on spin-dynamics of Fermi liquid ^{3}He in contact with solid ^{3}He-layers adsorbed on aerogel strands. These experiments have shown a $D_0 \sim T$ law for low T and hence that even in weakly polarized Fermi liquids spin-scattering becomes important at low T. We present a scattering model which describes the observed behavior.

Pulsed NMR-experiments were performed at 950 kHz. NMR-signals of bulk liquid ^{3}He and of ^{3}He immersed in aerogel [1] were measured simultaneously in separated NMR-coils. These coils were located in one cell which also hosted a Pt-powder sample for NMR-thermometry. The pressure in the cell was varied in the range 0.5 to 20 bar. The whole assembly was coupled by a Ag-heat-exchanger to a Cu-nuclei cooling stage with which the ^{3}He could be cooled down to 0.2 mK.

One- and two-pulse NMR-techniques were used to determine magnetization, spin-lattice relaxation T_1 and the spin diffusion coefficient D_0 for liquid ^{3}He in contact with the adsorbed ^{3}He-solid layers. For the measurements the field gradients (G_z) varied between 0.03 and 3 mT/cm. The spin-spin correlation time T_2 was determined by using a phase-correlated multi-pulse sequence. Details of the experimental set-up and measuring techniques are described elsewhere [2],[3].

Due to the rapid spin-exchange on the solid-liquid interface the coexisting solid- and liquid-contribution to the NMR-spectrum are merging. At temperatures below 15 mK the signal becomes dominated by the paramagnetic solid layer contributions which then can only be discriminated against the liquid due to the different spin-dynamics of solid and liquid. Below 15 mK any rf-excitation of the sample's magnetization leads to a complicated and non-exponential recovery curve in time. We obtain at short times T_{1S}=10 sK$^{-1} \cdot T$ and T_{2S}=3.3 ms+0.06 msK$^{-1} \cdot T$ which describe the recovery of the solid-layer magnetization. Relaxation times T_{1L}=13 sK$^{-0.5} \cdot T^{0.5}$ and

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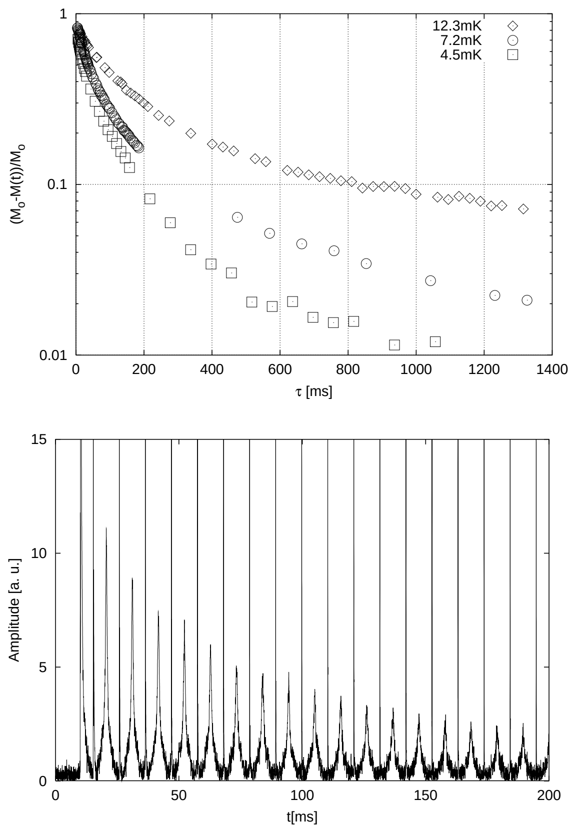

Fig. 1. Top: Temperature dependent T_1-recovery of the Free Induction Signal of solid (fast) and liquid (slow) ^{3}He at 20 bar after a $\pi - \tau - \frac{\pi}{2}$ excitation. Bottom: T_2-relaxation of spin-echo amplitudes in an alternating phase sequence $(\frac{\pi}{2}|_x - \tau - (\pi|_{(-1)^n x} - 2\tau)|_n)$. Data were taken at 20 bar and at 6.4 mK and hence, the visible decay is not affected by solid-layer contributions.

T_{2L}[ms]=100 ms+0.06 msK$^{-0.66}$ $\cdot$ $T^{0.66}$ are reached asymptotically which can be attributed to the spin-lattice and spin-spin relaxation of the liquid (see fig. 1).

Since T_{2L} is 30 times longer than T_{2S}, the field gradients could be adjusted in a way that spin-diffusion in the liquid still takes place at times when the solid signal has died away. Therefore two-pulse spin-echo experiments could be performed to determine D_0 of the liquid from the decay of echo amplitudes ($\sim exp(-\frac{2\tau}{T_{2L}} - \frac{2}{3}D_0(\gamma G_z)^2\tau^3$) with γ the gyromagnetic ratio of ^{3}He). The temperature and pressure dependence of the spin diffusion coefficient $D_0 = \frac{1}{3}v_F^2(1+F_0^a)\tau_{\text{eff}}$ are shown in fig. 2. τ_{eff} denotes the effective qp-collision time in spin diffusive transport phenomena (for bulk liquid $\tau_{\text{eff}} = \tau_D \sim \tau_{qp}$).

Since the measured decay of spin-echo amplitudes follow very well a τ^3-law, we can exclude effects of restricted diffusion (τ^1-law). Therefore we have to conclude that the decrease of D_0 with decreasing T (see

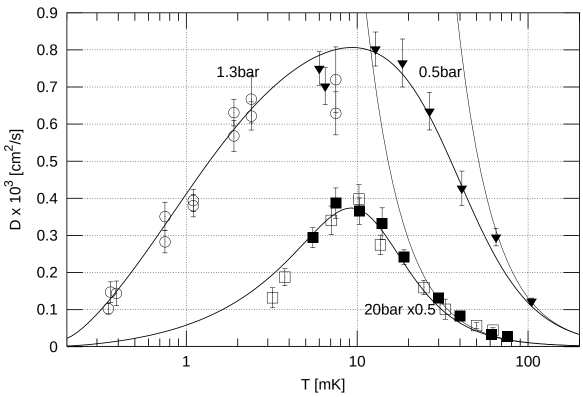

Fig. 2. Spin diffusion coefficient of normalfluid ^{3}He in aerogel at different pressures (20 bar data are scaled down by a factor of two for clarity). Different symbols refer to experiments in different gradients and pressures. The lines at high T show the T^{-2} behavior of the bulk Fermi liquid (measured data points are omitted for clarity). The two bell-shaped lines result from the scattering model described in the text. (Note, superfluidity of ^{3}He in aerogel is suppressed at 1.3 bar.)

fig. 2) is caused by an additional scattering process which we trace back to a spin-dependent effect which in turn leads to an additional scattering rate $\tau_{sp}^{-1} \sim P_{sp}$ with P_{sp} being the polarization of the adsorbed solid ^{3}He-layers. Quasi-particles from a volume $V_{ae} = \beta_{ae} \cdot v_F\tau_D$ [1] can reach these paramagnetic layers within a characteristic collision-time τ_{s0}. Within this model τ_{eff} can be written as $\tau_{\text{eff}}^{-1} = \tau_D^{-1} + \tau_{ae}^{-1} + (P_{sp}V_{ae}\lambda)/(\tau_{s0}(\lambda + v_F\tau_D))$ [4]. The bell-shaped curves of fig. 2 result from a fit of this model to the data, with λ and τ_{s0} being the only free parameters. We found the geometric mean free path λ as well as the strength of the spin-dependent scattering τ_{s0} pressure dependent. For 1 bar λ and τ_{s0} are 17 nm and 3 ps, and the values for 20 bar are 70 nm and 6 ps, respectively. Further experimental and theoretical investigations are required to understand these observations in detail. Nevertheless, these results might be of interest for other experiments on ^{3}He, e.g. NMR in high fields or vibrating wire experiments in the ballistic regime of qp-scattering. [2]

References

[1] from AIRGLASS, Staffanstorp, Sweden; characterized by: porosity α=96.8%, density ρ=0.071 g/cm^3 and surface to volume ratio β_{ae}=34$\cdot$10^6 m^2/m^3.

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