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"Ultra-low temperature magnetic properties of liquid 3He films"

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Ultra-low temperature magnetic properties of liquid ^{3}He films

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We report measurements of the nuclear magnetization of submonolayer liquid ^{3}He films adsorbed on a graphite substrate (Papyex) preplated by a monolayer of ^{4}He. In the submilliKelvin temperature range we observe a substantial enhancement of the nuclear magnetization with respect to the degenerate Fermi Liquid value. The unusual temperature dependence of this new contribution to the liquid ^{3}He film magnetization agrees well with that expected from the theory of weak disorder in two-dimensional (2D) correlated Fermion systems. The effects of disorder and reduced dimensionality suppress the superfluid transition at least to below $180\,\mu K$.

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1. INTRODUCTION

Liquid ^{3}He films adsorbed onto a graphite substrate provide a model system for highly correlated Fermions at reduced dimensionality. The first and second layer of adsorbed ^{3}He behave as two dimensional Landau liquids, in which the interaction can be continuously varied from an almost ideal to an extremely correlated Fermi liquid.[1-4] A linear temperature dependence of the heat capacity[1,2,9] and a constant susceptibility[3,4] are observed at low temperatures. For the second layer liquid, the density can be varied over a much larger range and susceptibility enhancement factors as high as 45 are found,[5] a factor of two higher than for the bulk system. In the present work, we report measurements of the nuclear susceptibility of liquid ^{3}He films down to temperatures as low as $180\,\mu$K. We observe for the first time a substantial enhancement of the nuclear magnetization with respect to the degenerate Fermi Liquid value in the submilliKelvin temperature region.

2. EXPERIMENTAL

The nuclear susceptibility of submonolayer ^{3}He films adsorbed onto a graphite substrate (Papyex) preplated by a monolayer of ^{4}He has been measured for several densities (0.036, 0.052, 0.058, and 0.063 Å^{-2}) in a temperature range extending from 500 mK down to 180 μK. The mass of the Papyex substrate was 0.632 g, corresponding to a surface area of 13.3 m^2 which was determined by a ^{3}He adsorption isotherm. The magnetization measurements were done by means of a CW-NMR spectrometer working at a frequency of 3.67 MHz, using a cold preamplifier situated in the helium bath. The temperature was measured using a Pt NMR thermometer, calibrated at high temperatures with carbon resistance and CMN thermometers. Preplating of the substrate with ^{4}He is necessary to suppress the paramagnetic susceptibility of the first layer, which in the case of the pure ^{3}He system would largely dominate that of the fluid overlayer, especially at low temperatures. The correct amount of ^{4}He is found by first adsorbing slightly less than 1 monolayer of ^{4}He together with a small amount of ^{3}He. From the magnetization of the ^{3}He atoms trapped in the first layer one can then determine the amount of ^{4}He necessary to complete exactly one monolayer. Using this procedure we obtain a density of the ^{4}He monolayer which is about 5% larger than that for ^{3}He, which is consistent with neutron data.[6] For the measurements we then used a coverage which was about 2% higher. The neutron incommensurate coverage scale[6] is used in this work.

3. RESULTS AND DISCUSSION

In Fig. 1 we show the magnetization as a function of temperature for different coverages. For the three lowest densities the ^{3}He film is liquid while for the highest density a solid-liquid coexistence is observed. The onset of solidification of the ^{3}He layer is located around a density of 0.060 Å^{-2}as determined from the sudden increase of the magnetization at low temperatures. The susceptibility of the liquid films is described well by the expression given in ref.[7] as shown in Fig. 1. For the coverage of 0.063 Å^{-2} a Curie-Weiss contribution was added in order to take into account the magnetization of the solid fraction. The Curie-Weiss temperature used for this fit, $\Theta = -1.5$ mK, was obtained from data at higher coverages (0.072 Å^{-2}) for which the film was completely solid. The effective Fermi temperatures obtained from these fits, shown in Fig. 2, agree extremely well with those measured for the pure

^{3}He system.[5] The same values of T_F^{**} are obtained by taking the ratio of $\chi(0)/\chi_0(0)$, where $\chi(0)$ is the susceptibility at $T = 0$ and $\chi_0(0) = C/T_F$ is the susceptibility of the ideal Fermi gas at the same density. In this case we take for $\chi(0)$ the value at the low temperature plateau (see Fig. 3).

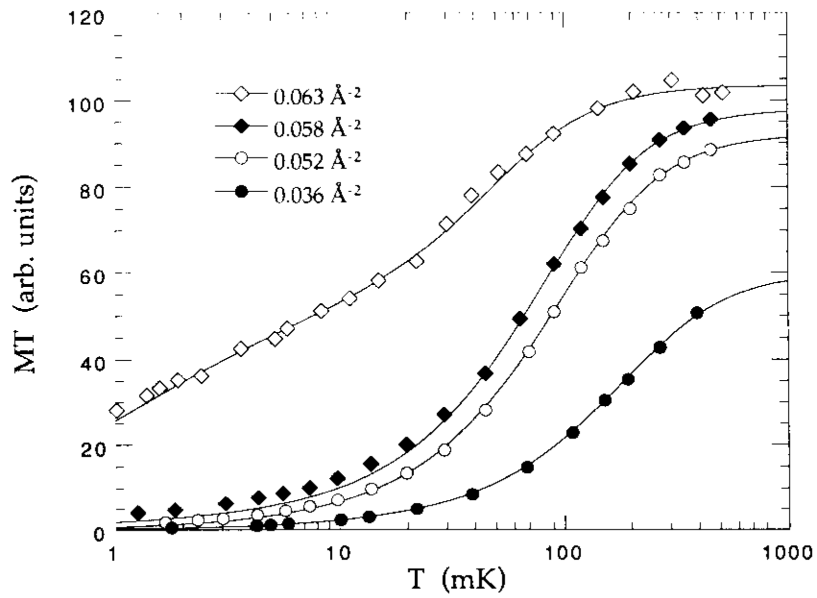

Fig. 1. Magnetization multiplied by temperature for ^{3}He films adsorbed on Papyex preplated by a monolayer of ^{4}He. The highest coverage is in the solid-liquid coexistence regime. The lines are fits to the data described in the text.

For the liquid on the 'melting curve' coverage of 0.063 Å^{-2} we find an effective Fermi temperature of 70 mK, in agreement with measurements performed on the pure ^{3}He system. This result confirms the high values we obtained for the susceptibility enhancement factors of highly correlated liquid ^{3}He films.[5]

Fig. 3 shows the magnetization for the three liquid coverages as a function of temperature emphasizing the behavior at low temperatures. We observe for the lowest density a small increase of the magnetization with respect to the degenerate Fermi Liquid value in the submilliKelvin temperature region. The effect becomes very significant as the coverage is increased. For the lowest coverage, the onset of this additional contribution is around 3 mK, i.e. about the same temperature T_k where Greywall observed a change in the temperature dependence of the heat capacity and which was attributed to a possible superfluid transition.[8,9] We observe however neither a frequency shift nor a change in the NMR lineshape for temperatures below 3 mK. These effects, together with the increase of the magnetization, are to our knowledge incompatible with a superfluid transition of the ^{3}He film.

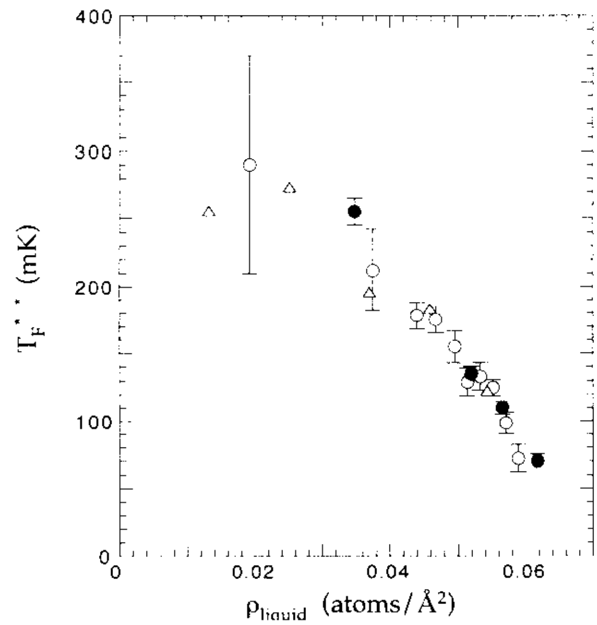

Fig. 2. Effective Fermi temperature T_F^{**} as a function of the liquid density. (△): ^{3}He/^{4}He/Gr, Lusher *et al.*[3]; (○): ^{3}He/^{3}He/Gr, Morhard *et al.*,[5]; (●): ^{3}He/^{4}He/Gr, this work.

Sheldon and Hallock[10] recently reported measurements of the spin diffusion, magnetization and NMR relaxation rates for ^{3}He films adsorbed onto a Nuclepore substrate preplated by about 2.5 layers of ^{4}He . Reducing the ^{4}He coverage, they observed a decrease in the diffusion coefficient and the appearance of a large Curie component in the magnetization of the liquid ^{3}He film. These effects were interpreted as an Anderson localization of the ^{3}He atoms due to the disorder introduced by the surface roughness of the substrate and the semisolid ^{4}He adjacent to it. In our case, the additional contribution to the magnetization occurs at much lower temperatures and has a much weaker temperature dependence. These qualitative differences can be explained in the framework of the Anderson localization model, but we must consider a different limit: weak disorder and high correlations. Sheldon and Hallock investigated a very low density (0.1 layer) ^{3}He film on a strongly disordered substrate. Here we deal with high density liquids on a weakly disordered substrate: the coherence length of the graphite substrate is on the order of several hundred Ångströms, and hence the mean free path of the ^{3}He quasiparticles is much larger than the Fermi wave-length, a typical situation of the Anderson weak localization problem.

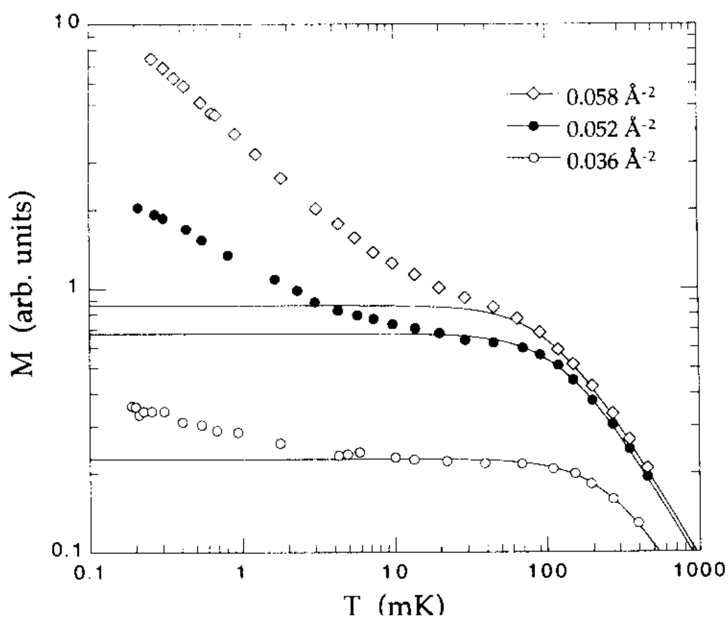

Fig. 3. Magnetization as a function of temperature for ^{3}He liquids of different densities. The solid lines are the same Fermi Liquid fits shown in Fig.1.

The interplay between correlations and disorder in fermionic systems has been investigated theoretically in electronic conductors.[11] The model predicts a logarithmic increase of the magnetization at low temperatures that agrees well with our experimental data. The effect is observed at low temperatures (in our case below several mK), when the quasi-particle mean free path is larger than the graphite platelets size.

4. CONCLUSIONS

We have measured the nuclear magnetization of liquid ^{3}He films adsorbed on graphite preplated by a solid monolayer of ^{4}He down to temperatures as low as 180 μK. The effective Fermi temperatures agree very well with previous data obtained for the pure ^{3}He system and confirm the high susceptibility enhancement factors obtained in that work. In the submilliKelvin temperature range we observe for the first time a substantial enhancement of the nuclear magnetization with respect to the degenerate Fermi Liquid value. This contribution grows with the correlations of the system. Its unusual temperature dependence agrees well with that expected from the theory of weak disorder in 2D correlated Fermion systems. Adsorbed liquid ^{3}He provides therefore a unique system to investigate the magnetic properties of weakly localized interacting fermions. The effects of disorder and reduced dimensionality suppress the superfluid transition at least to below 180 μK.

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