Pulsed NMR Studies of ^{3}He Films and Many Particle Exchange at Very Low Temperatures

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Introduction

The interpretation of measurements of the nuclear spin-spin relaxation times of ^{3}He in commensurate films of ^{3}He-Ne mixtures on boron nitride (BN) has been used to test the multiple spin exchange model for solid ^{3}He. In this model, the quantum tunneling of ^{3}He atoms in the 2D quantum solid consist of 2-particle, 3-particle, 4-particle, 5-particle and possibly higher order cyclic ring exchanges, all of which have comparable rates for a monolayer film and depend on the surface density.

Experimental

A coherent pulsed NMR spectrometer employing a quadrature hybrid tee bridge [1] tuned for 230 MHz was used to measure the nuclear spin-spin relaxation times, T_2, of ^{3}He for ^{3}He –Ne mixtures adsorbed as a commensurate film on BN. The Ne was admitted as low pressure gas via a heated capillary tube and adsorbed on the cold BN substrate maintained at approximately 3K by a weak link to a cold finger that was an integral part of a dilution refrigerator. This method was used to condense Ne atoms at random on the substrate before adding sufficient ^{3}He gas to complete a monolayer. The exact monolayer coverage was determined by observing the sharp minimum if T_2 at exact monolayer coverage [2-3] . The Ne atoms behave as inert objects as far as quantum tunneling is concerned and therefore interrupt the higher order exchanges much more significantly than lower order exchanges as a function of Ne concentration.

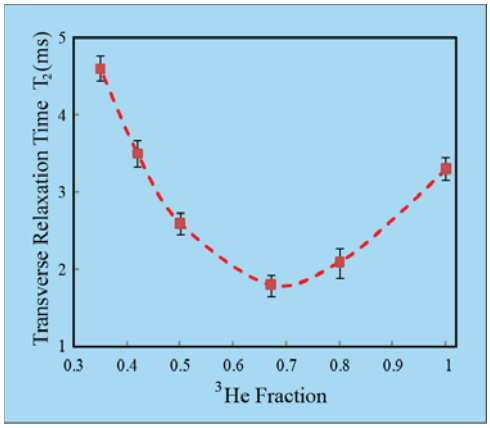

Figure 1. Variation of the nuclear spin-spin relaxation time, T_2, as a function of He coverage for a ^{3}He-Ne film on BN at 220 mK.

Results and Discussion

For a classical system, the spin-spin relaxation time at low temperatures for a dilute system would increase as the sample is diluted with $T_2 \sim 1/x$, corresponding to the decrease in the NMR second moment with the reduction in the concentration of the spin species. The opposite is observed for ^{3}He films for which the line width and T_2 is determined by the quantum tunneling that results in a significant motional narrowing of the line shape. For pure films it has long been conjectured that the tunneling motions consists of particle ring exchange in instead of simple Heisenberg-Van Vleck two-particle exchange and involves several high order exchanges and that these are of comparable strength. The results shown in Fig. 1 exhibit a strong minimum in T_2 corresponding to the competing signs of the two-particle (anti-ferro) and three-particle (ferromagnetic) exchange interactions. Below 50% ^{3}He concentration, two particle exchange dominates the relaxation process.

Conclusions

The dependence of the nuclear spin-spin relaxation times on Ne concentration for random ^{3}He-Ne mixtures formed as commensurate films on BN substrates are consistent with the multi-spin exchange model for 2D solid 3He.

References

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