Observation of Nuclear Spin Waves in Spin-Polarized Atomic Hydrogen Gas

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We have observed narrow, distinct resonances in the NMR spectrum of dilute spin-polarized atomic hydrogen gas ($n \sim 10^{16}$ atoms/cm^3). The dependence of the observed spectra on temperature, density, polarization, and magnetic field gradient is consistent with theoretical predictions for spin-wave excitations damped by diffusion. We have measured the parameter μ, which is a measure of the importance of exchange effects in spin-transport processes, and the diffusion coefficient D_0, both of which are in reasonable agreement with theory.

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We report the observation of a series of sharp, discrete resonance lines in the NMR spectrum of spin-polarized atomic hydrogen (H↓) (see Fig. 1). We interpret the observed spectra in terms of collective nuclear spin-wave oscillations in this rarefied gas.

Quantum mechanical exchange in degenerate systems (e.g., liquid ^{3}He and electrons in metals[1,2]) greatly alters the spin-transport properties and in particular causes these systems to exhibit spin-wave oscillations. Lhuillier and Laloë[3,4] have shown, however, that in a nuclear spin-polarized gas, even when the interactions are spin independent, exchange effects have a significant influence on the nuclear spin-transport properties when the thermal de Broglie wavelength $\lambda = \hbar(2\pi/mkT)^{1/2}$ becomes significantly larger than the atomic size d. Because of its low atomic mass and negligible attractive interaction, H↓ is expected[5] to remain a gas even at $T = 0$ K. Hence the condition $\lambda >> d$ can easily be satisfied long before degeneracy effects become important.

When two atoms with different nuclear spin orientations pass within one de Broglie wavelength of each other, exchange effects cause their spins to precess about one another. In the following Letter,[6] Lévy and Ruckenstein discuss spin transport in H↓ in terms of a quasiparticle description similar to Landau Fermi-liquid theory. They show that at the macroscopic level, exchange effects give rise to a precession of the spin current about a molecular field parallel to the nuclear spin density $\vec{\sigma}$. This produces the magnetization oscillations discussed by Lhuillier and Laloë.

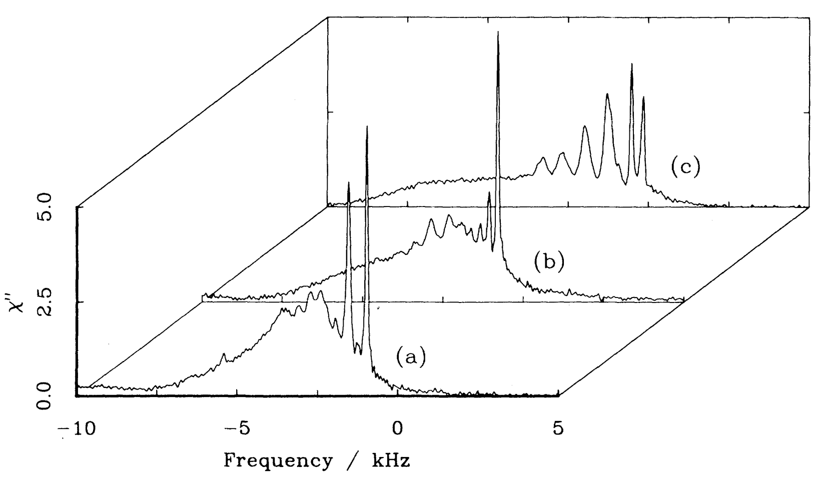

FIG. 1. H↓ NMR spectra showing the variation of the spectrum with the field gradient. The magnitude of the vectorial change in $\nabla\delta H_0(\vec{r})$ was about 0.4 G/cm between traces (a) and (b), and twice that much between (b) and (c). The initial magnitude and direction of $\nabla\delta H_0$ were not accurately known. The time between successive spectra is less than 2 min. All spectra were taken at $T = 245$ mK, $n = 3.2 \times 10^{16}$ atoms/cm^3, and $P \sim -1$ using tipping pulses of about 10°.