Luttinger Liquid Behavior of Helium-Three in Nanotubes

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Considerable experimental effort has been devoted to exploring the fundamental properties of one-dimensional (1D) systems in which strong correlations render all excitations to be collective. These systems are theoretically described in terms of a Tomonaga-Luttinger liquid (TTL) state, one of the few exact quantum mechanical solutions of a strongly-correlated system.

Helium-3 (^3He) adsorbed in mesoporous materials that contain nanoscale 1D channels can serve as a model system for studying TTL physics of uncharged systems. The line density can be varied in a controlled manner and NMR methods can measure particle dynamics over a wide temperature range.

NMR techniques - developed at the MagLab's High B/T Facility to enable high sensitivity measurements of the dynamics of atoms at very low temperatures - have been used to measure the thermal relaxation of ^3He atoms confined to the interior of "MCM-41" nanotubes at temperatures near the fermi degeneracy temperature, $T_F \sim 0.075K$.

The observed spin-lattice relaxation time (see Figure) shows the expected peak in the relaxation rate at the temperature $T=2T_F$, as well as behavior consistent with the expected linear decrease at lower temperatures, measured by NMR down to ~50mK, indeed, an extremely low temperature for successful NMR measurements! These results verify predictions of the landmark TTL theory for uncharged Fermi atoms confined to one dimension, i.e. within nanochannels featuring a diameter comparable to the atoms' deBroglie wavelength.

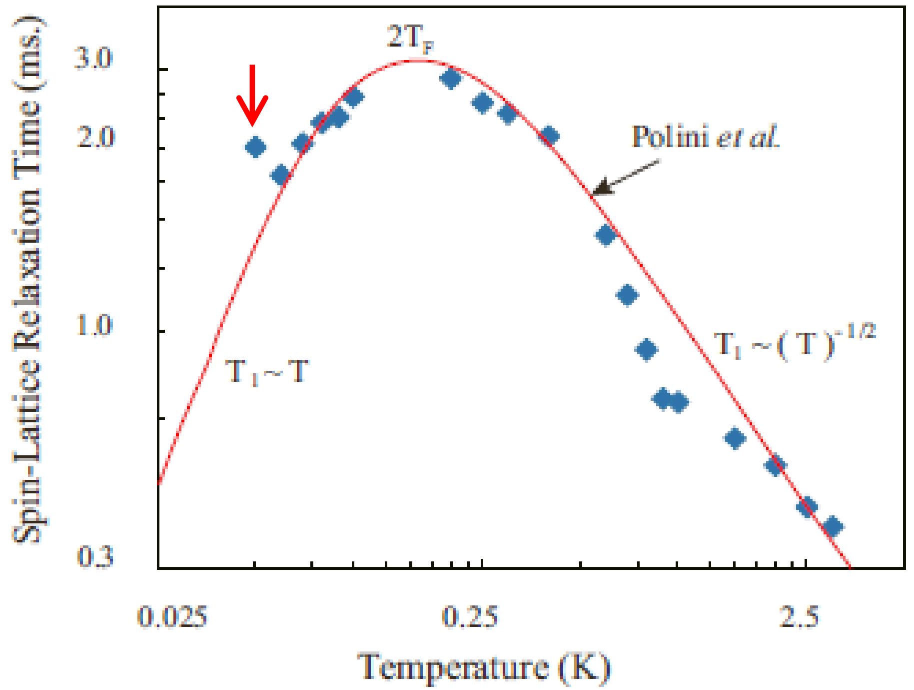

Figure: Temperature dependence of the nuclear spin-lattice relaxation time of ^3He atoms confined to the interior of ^4He-plated nanotubes of diameter comparable to the atoms' deBroglie wavelength. The solid red line is scaled from the calculations of Polini et al. [Phys. Rev. Lett. 98, 26403 (2007)]. The deviation at 0.4K (red arrow) is associated with the first excitation level for transverse motion in the tubes.

Facilities and instrumentation used: Bay2 of the High B/T Facilities were used for the measurements.

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