Luttinger Liquid Behavior of ^{3}He Atoms in a One-Dimensional Nanochannel

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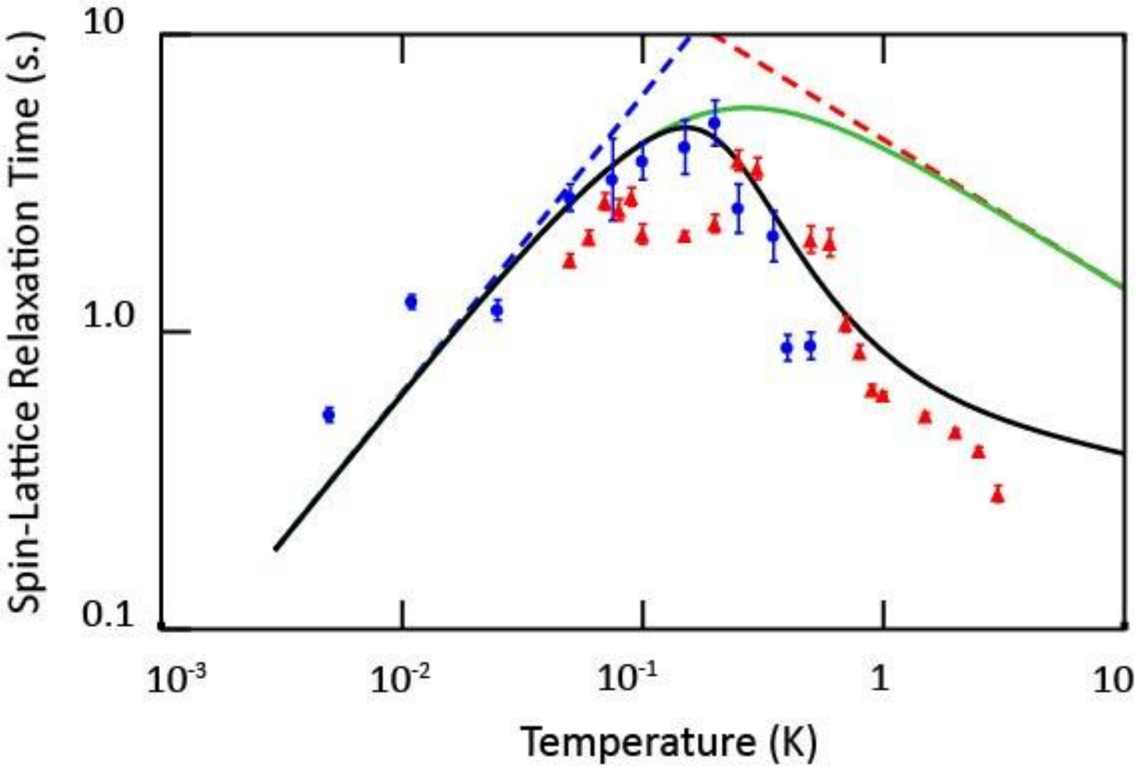
Although three-dimensional many-body systems can often be well understood by theoretical descriptions with quasi-particle excitations, in a one-dimensional (1D) world, quasi-particles do not exist due to strong interactions. Instead, the Luttinger Liquid theory was proposed to cast light on the dynamics of 1D systems. A variety of experimental studies have explored and tested the predictions of the Luttinger Liquid theory as it applies to electrons in quantum wells and wires. However, degenerate charged systems are prone to instabilities and there are few suitably degenerate charge-neutral systems that are experimentally accessible.

In this research, unique ultra-low-temperature nuclear magnetic resonance (NMR) methods are applied in the MagLab's High B/T facility to study the dynamics of ^{3}He atoms confined in the interior of 1D channels of a special mesoporous material known as MCM-41 (Mobil Composition of Matter Number 41) that have been pre-plated with ^{4}He atoms. Ultra-low-temperature NMR is able to probe this charge-neutral 1D system at temperatures comparable to and below the Fermi temperature, which is the regime in which the Luttinger liquid theory is expected to be valid. The measured spin-lattice relaxation times (T_1) are related linearly with temperature (T) when the temperatures are well below the degenerate temperature, which is a signature of Luttinger liquid dynamics. At higher temperatures, there is a peak at twice the Fermi temperature, followed by a decrease that fits the higher temperature data once the presence of transverse motions is taken into account.

This research is one of the first measurements of Luttinger liquid dynamics in a neutral fermion system well below the degeneracy temperature. It broadens the scope of 1D physics and calls for further investigation in this physical system that is dominated by quantum interactions.



The temperature dependence of the spin-lattice relaxation times (T_1) of a sample with Ag powder providing increased thermal anchoring (solid blue circles), compared to another sample without Ag powder (solid red triangles). The Ag powder was necessary to acquire data through the peak at twice the Fermi temperature and down to much lower temperatures. The green line is the theoretical dependence of a Luttinger liquid. The black line is the expected dependence once the lowest transverse mode is included.

Facilities and instrumentation used: MagLab High B/T Facility, Bay 2 Instrument.
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