Experimental report

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Proposal: **6-01-328**

Council: 4/2014

Title: Dynamic Structure of liquid 3He

Research area: Physics

This proposal is a new proposal

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Samples: 3He

Instrument	Requested days	Allocated days	From	To
IN5	6	5	05/07/2016	12/07/2016

Abstract:

The aim of this proposal is an investigation of the dynamics of bulk liquid 3He, a system where the interplay between statistics and interactions has been recently investigated theoretically in detail. The dynamical many-body theory (DMBT) presently yields accurate predictions for the dynamical structure factor, calling for neutron data of similar precision and resolution. This demanding task can be performed on the instrument IN5 of the ILL.

This particularly demanding experiment associates severe experimental conditions both in terms of neutron scattering and cryogenics. It has been successfully performed on the instrument IN5. We benefited from the expert technical help of Xavier Tonon, from the ILL cryogenic department. The data analysis is currently being performed in collaboration with the theoretical group of E. Krotscheck and T. Lichtenegger.

Neutron scattering: The measurements were done using the reflection geometry, in order to cover a large momentum range, essentially unexplored. An angle of 15.5° was selected by calculation, and carefully implemented during the installation of the cryostat on IN5 by using a scintillation camera. The effective area of the sample cell (i.e., within the neutron beam), was 40x71mm^2. The effective thickness of the sample, on the order of 0.1 mm, is determined by the absorption cross section of ^{3}He.

Two incident neutron energies (3.55 and 9 meV) were selected in order to cover a large energy and wave vector range, while keeping a good resolution (0.086 and 0.35 meV, respectively). Due to the very large absorption cross-section of ^{3}He, the measured signal is extremely weak. Scans were performed for the usual experimental conditions (vanadium, empty can and ^{3}He sample) at both incident energies.

Cryogenics: The ILL dilution refrigerator 144-IL-HV-70 was used for this experiment since it can accommodate large samples. It provides temperatures well below 100 mK, sufficiently low to explore the "zero temperature" properties of ^{3}He in the energy range under investigation (E~1meV). Fine capillaries were installed by X. Tonon in order to allow the condensation of ^{3}He in the sample cell. The system consisted of two independent pressure circuits, for security reasons, and also to avoid losing the valuable ^{3}He sample gas in case of blockage.

Sample cell: Due to the difficulties in reaching very low temperatures under neutron irradiation, it was necessary to design a sample cell of unusual geometry, while observing stringent cryogenic conditions. Sintered silver powder of area 10 m^2 ensured the thermal contact between the sample (14 cm^3 of liquid ^{3}He), and the OFHC copper body of the cell. The sintered silver and the copper are NOT seen by the neutron beam, thanks to a novel geometry for the cadmium masking. The liquid ^{3}He sample could be kept at mm distances from the sinter, and the thermal time constant under these conditions did not exceed 15 mn, which is exceptional. The heating due to the neutron capture by ^{3}He amounts to 1 μWatt. This large value is due to the high flux of IN5; it is comparable to the cooling power of the dilution refrigerator at 10 mK. At the operating temperature (~100 mK), this effect, as well as thermal gradients in the metallic parts, the contacts, and the ^{3}He sample itself, could be made negligible.

Measurements: Due to the limited time, experiments could be performed at a single pressure. The working pressure must be kept relatively low due to mechanical constraints imposed by the aluminium cell window. The value P=0.826 bars was used. It corresponds to the equilibrium pressure of the cell connected to the storage tank of 76 liters, kept open to the cell, for security, during the whole experiment. The volume of gas condensed in the cell was 9.1 liters NTP. A dipstick working in a 100 liters helium dewar was used to pressurize and condense the ^{3}He gas. .

Data treatment: the data were first treated using ILL software (LAMP), and then analysed with our own software.

Experimental results: The data obtained for S(Q,E) are of excellent quality, they represent a major improvement with respect to our former measurements on IN6 [Ref. 1-3], which were considered as the reference in the Quantum Fluids community.

The low intensity regions of S(Q,E) are now very sharp and well defined. This is the case even in the very low energy/wave-vector sector, where the experiment was NOT supposed to be optimized.

The most important result is the determination of a complete map of the dynamic structure factor S(Q,E) of liquid ^{3}He in a large range, showing with an unprecedented sensitivity, both the density and spin-density excitations.

The results can be compared to recent calculations [Ref. 4, 5] based on the dynamic Many-body theory. The intensity at low energies corresponds to magnetic fluctuations, called "paramagnons", known from earlier works. It is remarkable, however, that these excitations could be measured with high accuracy together with the density fluctuations (zero-sound) present at higher energies. The transition between a quantum collective behavior characterised by the presence of the paramagnon and the zero-sound modes, and an independent-particle behavior, marked by a "quasi-free atom" parabolic dispersion, is similar to what is observed in two-dimensional ^{3}He [Ref. 6].

We are presently working with the theory group (Prof. E. Krotscheck Universities of Buffalo, USA, and Linz, Austria) to analyze in detail this behavior, and compare to the case of superfluid ^{4}He we investigated recently [Ref. 7, 8]. The case of ^{3}He is of particular interest, since it gives access to the dynamics of highly correlated Fermi Liquids, more complex and sophisticated than correlated Bosons.

References

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