Neutron Scattering from Solid ^{3}He

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Abstract

Multiple spin exchange leads, according to present understanding, to a variety of magnetically ordered states in solid ^{3}He, depending on pressure and applied magnetic field. We report the status of experiments to directly determine these structures by neutron scattering. The large neutron absorption cross section, and associated sample heating, impose severe experimental demands on the design of the sample cell. We report on our proposed solution, including details of the sintered heat exchanger necessary to cool the sample, as well as the $PrNi_5$ nuclear demagnetization stage. The use of NMR in parallel experiments to characterise growth of the solid sample within the sinter is also discussed.

Key words: solid helium3, neutron scattering, NMR

The magnetic interaction leading to magnetic ordering in solid ^{3}He is believed to be a direct consequence of the exchange of particles on neighbouring sites. The theoretical interpretation of Roger *et al* [1] suggests that three- and four-particle exchange interactions should be dominant compared to both, Heisenberg nearest neighbour and higher order exchanges. The aim of our work is to determine the magnetic structures and investigate the exchange mechanism using neutron diffraction techniques.

Several experimental constraints have to be overcome [2]. When performing the neutron diffraction experiment, one difficulty arises from the heat input due to the large absorption cross section of ^{3}He. Each absorbed neutron triggers the nuclear reaction $n+^3\mathrm{He}\rightarrow{}^3\mathrm{H}+{}^1\mathrm{H}$ which releases 760 KeV of kinetic energy. With an absorbtion rate of 10^6 neutrons per second (full instrument flux) a power of the order of 120 nW is expected to be deposited in the sample cell. At the ordering temperature, which is of the order of 1 mk, this represents a relatively high heat input. In order to allow this heat to be absorbed in an appropriate cooling reservoir, we use a nuclear demagnetisation stage made of 0.86 mole of $PrNi_5$ which is a material with a large heat capacity due to its hyperfine enhancement factor [3]. In detail, the demagnetisation stage is distributed in 12 rods, each of them being soldered with cadmium to 6 silver wires, which are in turn welded to an annealed silver flange holding the sample cell. These wires have been annealed with a RRR of 2000 and a diameter of 1 mm in order to ensure a good thermal conductivity between the cell and the nuclear stage. In order to also improve the thermal conductivity between the sample and the cell body, the solid has been confined in a sinter. A compacted Pt-Ag powder has been chosen for its particularly large surface area

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when compared to more conventional heat exchangers (based on pure Ag or Cu powder) without sacrificing the thermal conductivity [4].

A key role of the sinter is also to absorb directly most of the energy caried by decay products (^{3}H+^{1}H) of the nuclear reaction. The mean free path of these products in Pt or Ag is of the order of 1-3 μm, which is an order of magnitude less than in ^{3}He. For the high packing density of the sinter (60%) and a porosity of the order of 1 μm, most of the captured energy is deposited in the sinter and not in the ^{3}He sample. By comparing the energy directly absorbed by the sample to the latent heat of the ordering transition, we can estimate the average time for the neutron experiment to be of the order of 10 minutes.

Another difficulty due to the large absorption cross section of ^{3}He is the weak intensity of the diffraction signal. To take advantage of the full neutron beam and to minimize its attenuation we use a flat sample cell as shown in Fig. 1. The effective sample thickness viewed

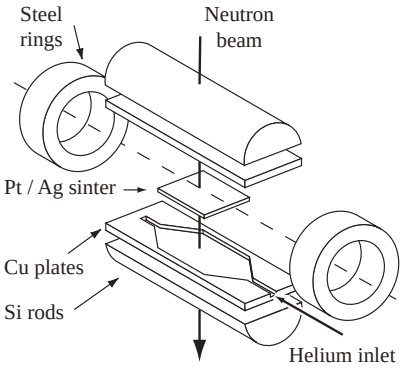

Fig. 1. Neutron cell

by the neutron beam is 100 μm with a surface area 26 mm^2. The sinter is pressed between two Cu plates sealed with solder. These plates are held together with Si bars (two half cylinders cut from the same single crystal) in order to sustain the pressure required to solidify the sample. With two nonmagnetic stainless steel rings tightening the Si bars from each side, the cell has been designed to sustain a pressure up to 200 bars, also allowing measurements in the high pressure magnetic phase.

One of the last difficulties is that the sample has to be grown and characterized *in situ*. Previous experiments have shown the possibility of growing single crystals within the sinter [5]. However, there are only a few studies of the properties of solid ^{3}He inside such a confined geometry. Independent experiments using the NMR technique have, therefore, been initiated in order to characterize the sample and to find the optimum technique for growth. An NMR cell has been constructed with the same type of sinter as that used for the neutron scattering experiment (Fig. 2) with a filling line equipped with heaters and thermometers to enable growth of the sample at constant pressure as well as the usual blocked capillary method. During the

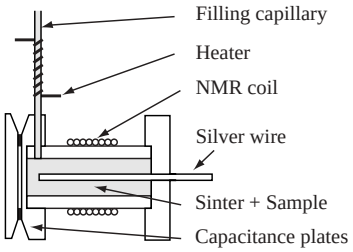

Fig. 2. NMR cell

crystal growth, the pressure can be controlled using a compact *in situ* strain gauge.

In the the low-field ordered phase, dipolar interactions lead to frequency shifts in the NMR spectrum, which depend on the orientation of the 3 possible magnetic domains existing in each crystal with respect to the static field [6]. The number and orientation of these crystals can, therefore, be determined by a careful analysis of the NMR spectrum. The frequency of the continuous wave NMR spectrometer which uses a single excitation/detection coil has been chosen to be of the order of 100 kHz. This allows the rf field to penetrate the sinter through several millimeters. The consequence is that only the low frequency branches of the NMR spectrum are accessible (the high frequency branches being of the order of 1 MHz). However, the components of the dynamic susceptibility tensor have been calculated to check the spectral weight of these lines.

We have already monitored the solidification process in different parts of the cell using neutron transmission measurements. The formation of the solid first in the bulk, and then in the sinter was measured and the redistribution of ^{3}He in the cell monitored in this process. Details of the neutron scattering experiments will be presented elsewhere. This work is supported by the European Union under FP5 Research Network Contract HPRN-CT2000-00166.

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