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NUCLEAR SPIN RELAXATION AND ATOMIC MOTION OF $^3$He ADSORBED ON GRAFOIL

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Résumé.- Les temps de relaxation de spin nucléaire, $T_1$ et $T_2$, de $^3$He adsorbé sur du Grafoil ont été mesurés. Les mécanismes de la relaxation ont été discutés en termes du mouvement des atomes à deux dimensions.

Abstract.—Measurements of the nuclear spin relaxation times, $T_1$ and $T_2$, have been made on $^3$He films adsorbed on Grafoil. From the results the relaxation mechanisms are discussed in terms of the two-dimensional atomic motion.

The aim of this paper is to obtain microscopic information of the atomic motion in $^3$He films adsorbed on Grafoil by spin-echo NMR experiments. The longitudinal and transverse relaxation times, $T_1$ and $T_2$, of $^3$He were measured at 10 MHz as functions of temperature $T$, the fractional coverage $X$, and the angle $\theta$ between the external field direction and the surface of the Grafoil. Typical experimental results are illustrated in figures 1 and 2.

Fig. 1: $T_1$ as a function of the fractional coverage for various temperatures.

In the following the data for three different regions of $X$ are discussed separately.

Fig. 2: $T_2$ as a function of the fractional coverage for various temperatures.

LOW COVERAGES, $X \leq 0.5$.

According to the specific heat results, the system behaves as quantum gas. In this region $T_1$ does not vary with $\theta$, whereas $T_2$ increases as $\theta$ is increased from $0^\circ$ to $90^\circ$. These $\theta$-dependences and the data shown in figures 1 and 2 suggest that the dipole-dipole interaction between $^3$He nuclei does not give rise to the principal mechanism for $T_1$ and $T_2$. The most probable relaxation mechanism concluded from examination of various models is: $T_1$ is determined by collision of $^3$He atoms with solids at the...
grain boundaries in Grafoil where $T_1$ is limited by interaction with magnetic impurities adsorbed at the boundaries, $T_2$ is determined by diffusion of $^3$He spins in the magnetic field gradient due to irregular orientation of the graphite grains.

**INTERMEDIATE COVERAGES, $0.5 \leq X \leq 0.7$.**

This region is characterized by the ordered lattice gas phase which appears below 3 K in a narrow interval of $X$ centered at about $X = 0.60$ /1/. The observed $\phi$-dependences of $T_1$ and $T_2$ are similar to those for $X \leq 0.5$. The temperature variation of $T_1$ can be explained by assuming a mechanism similar to that for $X \geq 0.7$, i.e., the motion of vacancies modulates the $^3$He dipolar interaction. The formation energy $\phi$ and the jumping frequency $\omega_0$ of these vacancies for $X = 0.58$ are found as $3.8 K$ and $5.6 \times 10^{13}$ s$^{-1}$, respectively. This value of $\phi$ remains constant between $X = 0.52$ and 0.60. As shown in Figure 2, there is a dip at about $X = 0.58$ in the $T_2$ vs $X$ curve below 3 K. Since $T_2$ for $0.5 \leq X \leq 0.7$ is explained by the same mechanism as that for $X \leq 0.5$, the dip can be attributed to a decrease of the mobility (i.e., the diffusion coefficient $D$) of $^3$He atom at $X = 0.58$. This seems to be associated with the formation of the ordered gas phase.

**HIGH COVERAGES, $0.7 \leq X \leq 1.0$.**

According to the specific heat studies, /1/ the two-dimensional solid exists above the melting line shown in Figure 3. The temperature variation of $T_1$ in the high concentration region is explained by vacancy modulation of the dipole-dipole interaction between $^3$He nuclei, the same mechanism as that for bulk solid $^3$He /2/. The value of $\phi$ obtained from $T_1$ data has the same order of magnitude as that of bulk solid $^3$He and increases as $\exp(X \uparrow)$ up to $X \approx 1.0$ where it decreases abruptly. The minimum values of $T_1$ (c.f. Figure 1) are in agreement with those expected from the BPP theory for two-dimensional system. Since $\omega_0$ should be equal to unity at the minimum, the line $T_1\left(\min\right)$ in Figure 3 is equivalent to the line for $\tau_1 = 1.6 \times 10^{-8}$ s. No discontinuous change in NMR is observed at the melting point in contrast to bulk solid $^3$He.

![Fig. 3: Phase diagram for high coverages.](image)

The results presented here are in agreement with those of Cowan et al /3/ obtained at lower frequencies. Details of this work will be published shortly, including the results on multilayer films not discussed here.

**References**

