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NON-RESONANCE MEASUREMENT OF THE NUCLEAR SUSCEPTIBILITY AND RELAXATION TIME OF LIQUID ^{3}He

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We have used a manometer method to measure for liquid ^{3}He the ratio of the nuclear paramagnetic susceptibility χ_p to that of the atomic diamagnetic susceptibility χ_d. We have also measured the nuclear relaxation time T_1 as a function of field up to 13.6 Teslas.

The apparatus (1) is shown in Fig.1. A capacitor made of metallized glass plates (51 μm separation between metal surfaces) was sealed along the sides but open at top and bottom. The capacitor was positioned vertically in a rectangular slot in a cylindrical iron shield. A stainless steel cylinder (1.27 cm o.d.) formed a chamber into which the ^{3}He was condensed through a stainless capillary. A capacitance bridge was used to measure the liquid level between the capacitor plates. The liquid level in the capacitor at zero magnetic field rose to about 1.4 cm above the liquid level in the outer container because of surface tension. When a uniform magnetic field B (larger than the saturation field of the iron (≃ 2 T) is applied in the vertical direction, the magnetic field inside the Fe shield is nearly uniform over a distance of about 0.55 cm and is less than the magnetic field at the lower surface by a constant amount $\Delta B \simeq 0.6$ T. The equilibrium change in height of the liquid in the capacitor is given in mks units by (1)

$$\Delta h = -\frac{\chi}{\mu_o g}[(B_2 - B_1)\Delta B] \qquad (1)$$

where Δh is the change in the liquid level in the capacitor when the applied field is changed by an amount $B_2 - B_1$, χ (assuming $|\chi| << 1$) is the magnetic susceptibility per unit mass and g is the acceleration of gravity. The total susceptibility of ^{3}He is the sum of the atomic diamagnetism χ_d and the nuclear paramagnetism χ_p, which obeys Curie's law near 1.3 K. The orientation of the nuclear magnetic moment has a relaxation time T_1 which has been measured (2-4) in bulk ^{3}He to be about 300 s. On such a time scale the response of the atomic diamagnetism is instantaneous.

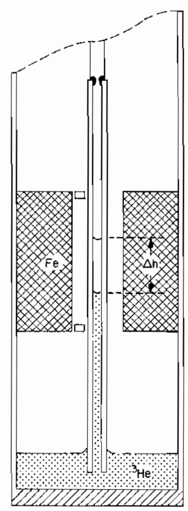

Fig. 1. Susceptibility measuring apparatus.

A measurement consists of rapidly changing the magnetic field and recording the capacitance change ΔC vs time. An example is shown in Fig. 2. The field is increased from 10.09 to 12.24 T in 17 s. Since $\chi_d < 0$ the liquid level increases as indicated by the proportional increase in ΔC. After the field sweep stops, the level decreases as χ_p relaxes to its equilibrium value at the high field. The relaxation of the liquid level is exponential and is a measure of the nuclear relaxation time T_1. If ΔC after the field reaches B_2 is extrapolated back to $t = 0$ we obtain a value which is proportional to h_o, the change in h as if the magnetic field change were instantaneous. $h_o - h_1$ is proportional to χ_d. $h_o - h_\infty$ (where h_∞ is the asymptotic level for $t \to \infty$) is proportional to χ_p. The ratio $\alpha = -\chi_p/\chi_d$ is very nearly independent

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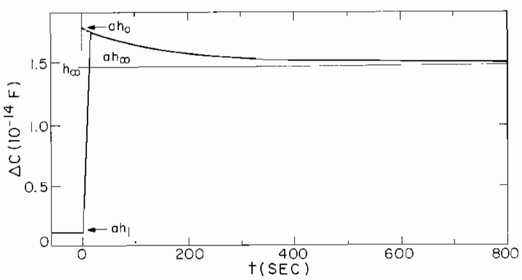

Fig. 2. Change in capacitance (ΔC ∿ Δh) for field change from 10.09 to 12.24 T in 17 s.

of the absolute calibration of h vs B. Figure 3 shows a relaxation when B is rapidly decreased from 12.3 to 10.1 T. The relaxation in this case is in the opposite direction as expected. The values of α obtained in increasing

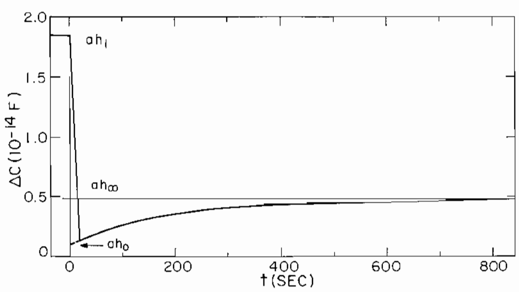

Fig. 3. ΔC vs t for a field change from 12.3 to 10.1 T in 17.4 s.

and decreasing the field were not significantly different, which shows that thermal relaxation effects are not important.

The average of the present measurements at 1.3 K at the saturated vapor pressure gives:

$$\alpha = -\chi_p/\chi_d = 0.205 \pm 0.013.$$

This value can be compared to values deduced from previous measurements of χ_p (5) and χ_d (5,6) for a molar volume of 37.21 cm^3 at 1.3 K.

$$\alpha_1 = 0.187 \pm 0.004 \quad \text{(ref. 5)}$$
$$\alpha_2 = 0.192 \pm 0.007 \quad \text{(ref. 5,6)}$$

In 18 measurements over fields from 2 to 13.6 T there was significant dependence of T_1 on B as shown in Fig. 4. The field dependence of T_1 is perhaps a boundary relaxation effect (7) which saturates at high fields since the value of T_1 at 13.6 T is apparently approaching the accepted value of the bulk relaxation time in bulk liquid ^{3}He.

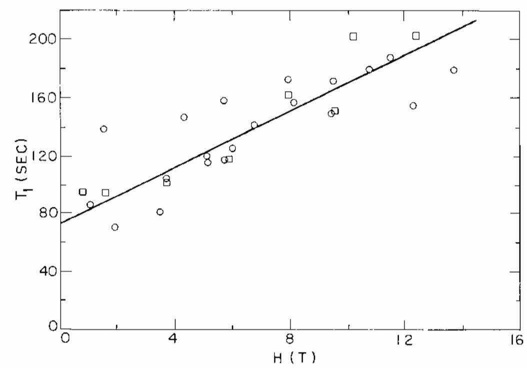

Fig. 4. T_1 as a function of magnetic field. ○ Present measurements; □ NMR measurements, ref. (8).

With improvements in the apparatus design the probable error of 6% could probably be greatly reduced. The method can give an absolute value of χ and is specially adapted to working in the highest field magnets (30 T) where resonance measurements are not feasible. It may be useful in measuring T_1 at temperatures below 0.5·K where the relaxation times are presumably very long.

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