Interaction of the liquid ^{3}He spins with the spins of ^{1}H nuclei at the wall

I. S. Solodovnikov and N. V. Zavaritskiĭ

P. L. Kapitsa Institute of Physics Problems, Russian Academy of Sciences, 117973, Moscow, Russia

(Submitted 8 July 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **56**, No. 3, 165–168 (10 August 1992)

A considerable decrease in the longitudinal magnetization of liquid ^{3}He nuclei, as a result of application of an rf field on the spins of protons in the walls of the experimental chamber, has been observed. This effect increases as the temperature is lowered from 0.2 K to 0.05 K.

The surface magnetic properties of ^{3}He atoms, which are situated near dissimilar walls, have been studied in Refs. 1–5. The interaction between ^{3}He spins and ^{19}F nuclear spins of the substrate in Teflon powder was studied in detail in Refs. 1 and 2. The ^{3}He–^{169}Tm coupling was studied in Ref. 3. The spin-lattice relaxation time, T_1, of the nuclear magnetic moments of various atoms at the surface, which is governed by liquid ^{3}He, was measured in Ref. 4. The results of these measurements are explained on the basis of the assumption that the coupling between the ^{3}He spins and the nuclear spins of the substrate occurs because of the dipole–dipole interaction between them, which is modulated by the motion of the helium atoms in the skin layer; this mechanism is the same for all types of walls. An additional channel for coupling of spin systems may arise in a substrate which contains electron paramagnetic impurities.[2] In a liquid helium–proton system of a porous polycarbonate material, however, the interaction was found to be weaker[5] than that of ^{3}He–^{19}F by a factor of 10^2. In our experimental study we determined the coupling of liquid ^{3}He spins with the ^{1}He spins from the effect of proton NMR saturation at the surface of the walls of an experimental chamber on the magnetization of ^{3}He.

The measurement volume of the chamber, made from a *Staycast-1266* epoxy resin, was 12 mm long and 4.3 mm in diameter. The inner walls of the chamber were coated with a thin layer of preliminarily evacuated resin. The cell was cooled in a ^{3}He–^{4}He dissolution refrigerator by means of copper wires which were tinned with a superconducting alloy and cemented to the cell wall. Between these wires we cemented the same kind of wires, whose temperature was measured with a carbon thermometer. The geometry of the experiment was such that the possible heating of the sample by the rf field could be controlled. The experimental gas used in the bulk of the experiments contained $\leqslant 0.01\%$ ^{4}He. In the course of filling the cell, this gas was passed through a filter made from a silica-gel powder, whose surface area was ~ 50 m^2. This filter was held at a temperature in the range 0.1–0.15 K. The ^{4}He impurity, whose presence is possible, was absorbed by the filter designed to adsorb principally ^{4}He.[6] During the experiment, the liquid was held at a pressure of 2–10 torr. The static magnetic field $\mathbf{H}_0$, which was oriented along the measurement-volume axis, was applied at a high temperature of the cell. The magnetic field was captured by a tube made from niobium foil as the cell was cooled. The relative nonuniformity of the field along the length of the sample was $\sim 5 \times 10^{-4}$. Two intersecting superconducting coils, which produced the rotating rf field, h_1, were placed at right angles to $\mathbf{H}_0$. The pickup coil of the flux transformer, which was linked with an rf SQUID used for measuring the magnetic moment, M_z, of the sample parallel to $\mathbf{H}_0$, was embedded in the wall of the experimental chamber.

At the chosen temperature, several rapid adiabatic sweeps of the ^{3}He NMR line were made by sweeping the frequency of the rf field. The equilibrium magnetic moment of the sample, M_0, and the spin-lattice relaxation time, T_1, were determined from the change in the longitudinal magnetic moment of the sample during the line sweeping, which was measured by the SQUID. The method described in Ref. 7 was used in the calculations. The values of T_1 lie between 3 min and 9 min. To determine the interaction between the ^{3}He spins and the ^{1}H nuclei of the substrate, we used the continuous rf field which rotated at a frequency close to the NMR frequency of protons. The rf frequency was turned on in a time of $\sim 3T_1$ of ^{3}He. We then measured the established longitudinal magnetic moment of the sample, M_z, by means of rapid adiabatic sweeping of the ^{3}He NMR line.

The plot of M_z versus the frequency of the rf field is shown in Fig. 1. The magnetic moment of helium was found to decrease at frequencies corresponding to the NMR of protons. This behavior suggests that there is a coupling between the ^{1}H and ^{3}He spin systems. For comparison we show in the lower part of Fig. 1 a frequency dependence of the change in the longitudinal magnetic moment due to the cell walls of a cell devoid of liquid helium, measured after the application of a short rf field pulse. This curve represents the shape of the NMR line of protons. In magnetic fields of 22 Oe and 44 Oe we detected, from the decrease in the magnetic moment of helium and from the response of the empty cell, the proton resonance line at the double Larmor frequency, which was studied[8] in deteail for the *Staycast-1266* epoxy resin.[1)] The spin-lattice relaxation time of protons, T_{1p}, which was determined from the time it took the

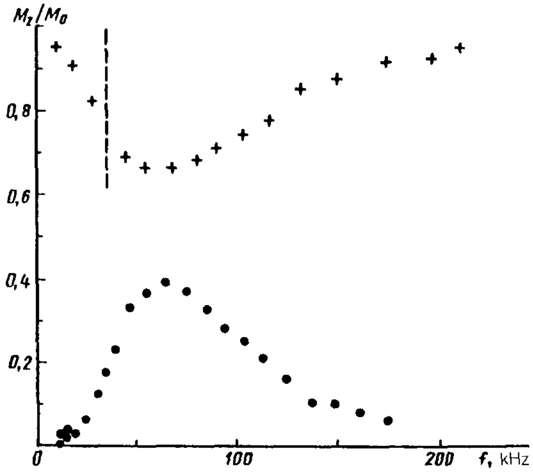

FIG. 1. The plus signs represent the magnetic moment of the liquid ^{3}He sample in the presence of an rf field, $H_0 = 11$ Oe, $h_1 = 0.10$ Oe, $T = 0.11$ K; the dashed line denotes the NMR frequency of ^{3}He; and the filled circles represent the proton NMR signal at the cell walls (in arbitrary units).

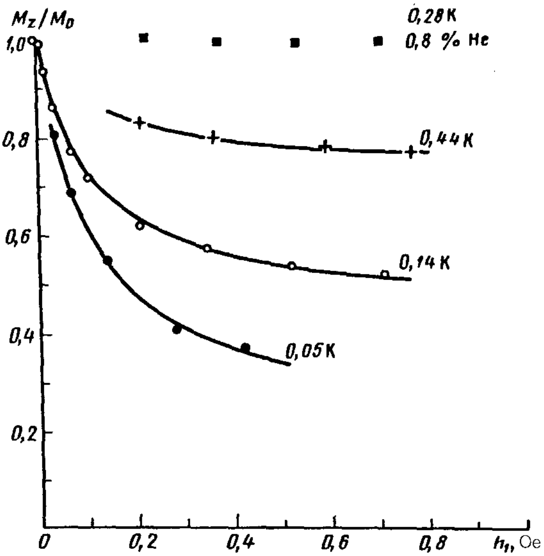

FIG. 2. Magnetic moment of the liquid ^{3}He sample versus the rf field, $H_0 = 11$ Oe; the frequency of the rf field is 55 kHz. The curves are an approximation of expression (1).

magnetization of the empty cell to be restored after the removal of the rf pulse, was ~ 1 min.

The plots of M_z versus the rf field of a frequency corresponding to the maximum proton resonance are shown in Fig. 2. The decrease in the longitudinal magnetization can be observed only when a purified ^{3}He is used. The deviation of M_z from M_0 is within the measurement error when ^{4}He is added to the experimental gas. This result indicates that the coupling between the spin systems of protons and ^{3}He is broken, evidently because of the ^{4}He film which coats the cell walls, and that the sample is heated only slightly by the rf field.

The proton resonance inside the walls was completely saturated at all the values of h_1 used by us, since the parameter which determines the saturation is $(\gamma_p h_1)^2 T_{1p} T_{2p} \gg 1$ even when $h_1 > 10^{-2}$ Oe. Here γ_p is the proton gyromagnetic ratio, and $T_{2p} \sim 10^{-5}$ s is the transverse relaxation time of protons. The magnetization of protons near the surface may be nonvanishing because of their coupling with spins of the liquid. At small values of h_1, the deviation of M_z from M_0 is proportional to h_1, which is probably due to the diffusion of the magnetization in the spin system of protons from the surface into the wall. A further increase of h_1 causes the ratio M_z/M_0 to reach a plateau of height R. The value of R determines the magnetic moment of the liquid ^{3}He sample under the conditions of complete saturation of the spin resonance of the ^{1}H nuclei at the surface of the walls. The $M_z(h_1)$ curves were approximated using the expression

$$\frac{M_z}{M_0} = \frac{1 + aRh_1}{1 + ah_1}. \qquad (1)$$

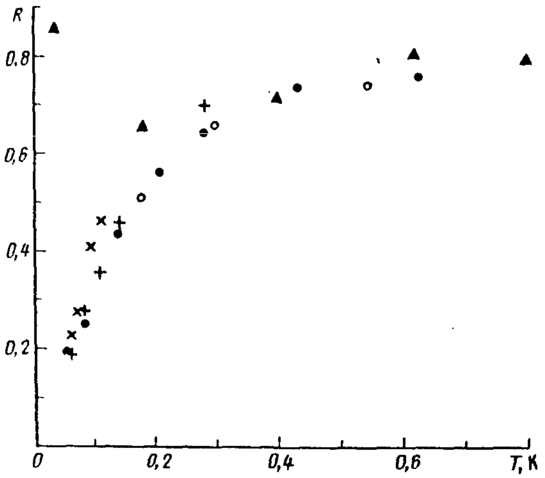

FIG. 3. Relative magnetic moment of an ^{3}He sample in the case of total saturation of proton NMR at the cell walls at various values of H_0. ○—5 Oe; ●—11 Oe; +—22 Oe; ×—44 Oe; ▲—data of Ref. 1 for a (liquid helium)—(Teflon powder) system, $H_0 = 15.4$ kOe.

The values of R do not depend on the strength of the magnetic field in the field range investigated by us (Fig. 3). At $T \gtrsim 0.2$ K, the value of R increases slowly with increasing temperature. The increase in R can be attributed to the engagement of the bulk mechanism of the spin-lattice relaxation of ^{3}He, which decreases the deviation of the magnetic moment of helium from the equilibrium value at the point the proton NMR reaches saturation at the surface of the walls. At $T \lesssim 0.2$ K we see a rapid decrease in the value of R with decreasing temperature. Such a behavior is at variance with the data obtained for a ^{3}He–^{19}F system in Ref. 1 (Fig. 3). The model for the coupling of the spin systems of the substrate nuclei and the liquid, which was proposed by us for the best description of the experimental results, assumes that the interaction occurs between the atoms of the first layer of the substrate and the first layer of solid helium at the surface, because of the motion of the atoms of this layer. This model accounts for the absence of the temperature dependence of R at temperatures below 0.5–1 K, at which the motion of atoms in the layer of solid helium does not depend on the temperature.[2,4] This description clearly is at odds with the results obtained by us.

We wish to thank V. I. Marchenko for a discussion of this study.

[1)] The decrease in the magnetic moment of helium at a frequency of the rf field equal to double the Larmor frequency of ^{3}He did not exceed the measurement error.

---

[1] A. Schuhl, F. B. Rasmussen, and M. Chapellier, J. Low Temp. Phys. **57**, 483 (1984).
[2] Q. Geng, M. Olsen, and F. B. Rasmussen, J. Low Temp. Phys. **74**, 369 (1989).
[3] A. V. Egorov, O. N. Bakharev, A. G. Volodin *et al.*, Zh. Eksp. Teor. Fiz. **97**, 1175 (1991) [Sov. Phys. JETP **70**, 658 (1991)].
[4] O. Gonen, P. L. Kuhns, C. Zuo, and J. S. Waugh, J. Magn. Reson. **81**, 491 (1989).
[5] D. R. Swanson, D. Candela, and D. O. Edwards, J. Low Temp. Phys. **72**, 213 (1988).
[6] K. Thompson, J. Low Temp. Phys. **32**, 361 (1978).
[7] I. S. Solodovnikov, Zh. Eksp. Teor. Fiz. **100**, 189 (1991).
[8] L. Scrbek, J. Sebek, and R. S. Safrata, Phys. **B165–166**, 919 (1990).

Translated by S. J. Amoretty