for bcc ^{3}He as well as for further sound-velocity measurements.

If the above supposition is correct, then the decrease in Θ_D for helium is related to the crystal structure rather than to the particular isotope. The work is being extended to hcp ^{3}He to investigate the temperature dependence of Θ_D in this phase.

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NUCLEAR ANTIFERROMAGNETISM IN SOLID He³†

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The nuclear magnetic susceptibility of pure solid He³ (1×10^{-5} He⁴ impurity) at molar volumes of 23.3, 23.6, and 24.2 cm³/mole has been measured between 0.2 and 0.04°K. Antiferromagnetic nuclear ordering is indicated with the Néel temperature T_N increasing from $(0.75 \pm 1) \times 10^{-3}$°K at 23.3 cm³/mole to $(2.4 \pm 1) \times 10^{-3}$°K at 24.2 cm³/mole. Special attention has been given to thermal equilibrium.

For many years the nuclear magnetic properties of solid He³ have been under intensive theoretical[1-8] and experimental[9-23] investigation in hopes of studying nuclear spin ordering at experimentally realizable temperatures. In most solids the dominant interaction between spins is the dipole-dipole interaction, which should produce ordering temperatures of about 10^{-6}°K. However in solid He³ the large zero-point energy en-

hances the spin-exchange interaction such that the ordering temperature should be on the order of 10^{-3}°K.[1-8, 11-17]

Earlier nuclear susceptibility measurements[9,10,13,20] have yielded various inconclusive results which are now thought to be due to poor thermal equilibrium in some cases and He⁴ impurities in other cases. We have taken special precautions to circumvent these difficulties. Refrigeration was by
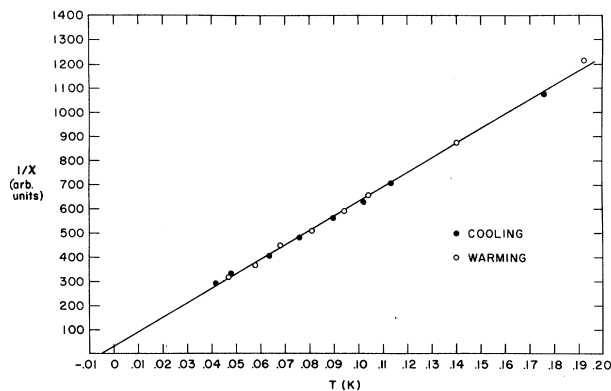
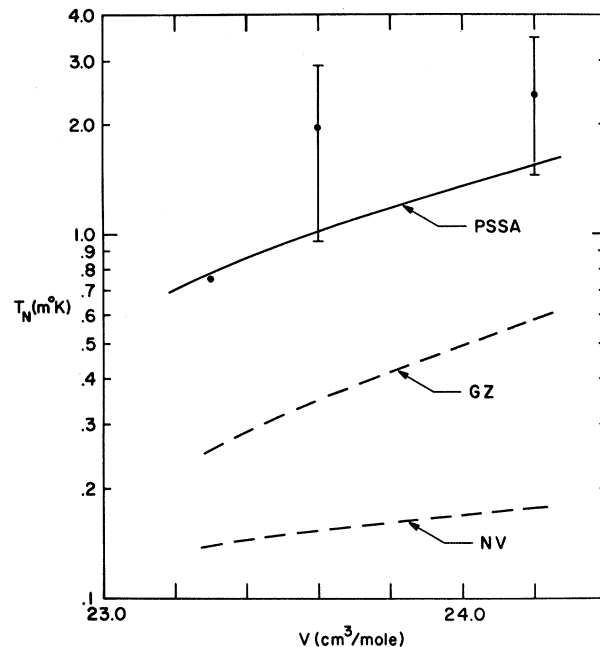FIG. 1. Inverse susceptibility of solid He^3 versus temperature at a molar volume of 23.6 cm^3/mole.

FIG. 2. The Néel temperature of solid He^3 versus molar volume. The solid curve is experimental work by Panczyk et al. (PSSA) (Ref. 17). The two dashed curves are the theories of Guyer and Zane (GZ) (Ref. 8) and Nosanow and Varma (NV) (Ref. 7).

means of a continuously operating dilution refrigerator and the temperature was stabilized with an electrical heater. The heater was located a fair distance from the sample chamber to avoid local heating.

Thermometry was accomplished by measuring the nuclear resonance absorption in a bundle of copper wires in thermal contact with the thermal link between the mixing chamber of the dilution refrigerator and the He^3 sample. The copper thermometer was located about 5 mm from the sample. It was calibrated at 0.4°K against a carbon resistance thermometer.

The sample volume was about 0.05 cm^3 and had a contact area with the thermal link of about 100 cm^2, accomplished by means of a sintered copper sponge. The He^4 impurity of the sample was reduced by fractional distillation and was measured by means of a specially modified CVC 24-210B leak detector. This impurity was found to be $(1 \pm 3) \times 10^{-5}$.

The nuclear susceptibility of the sample was measured by cw nuclear resonance absorption. Extensive checks were made for saturation both in the susceptibility measurements and the temperature measurements.

Thermal equilibrium was established by changing the temperature very slowly in 0.01°K steps and allowing 20 min to 1 h for equilibrium at each temperature. Data were taken during both warming and cooling to check for thermal hysteresis. Also measurements were made at widely separate times while the temperature was held constant.

At all three molar volumes the data were found to fit the Curie-Weiss law $\chi = C/(T + \theta)$ with Weiss θ's of (15.2 ± 2), (3.98 ± 2), and $(4.89 \pm 2) \times 10^{-3}$ °K at 23.3, 23.6, and 24.2 cm^3/mole, respectively.

The data for 23.6 cm^3/mole are shown in Fig. 1. The positive values for the Weiss θ's at all three molar volumes indicates that the ordering in solid He^3 at low density will be antiferromagnetic. In Fig. 2 our measured values for the Néel temperature are compared with those of Panczyk et al.,[17] calculated from their data on the expansion coefficient of solid He^3. Also included are the theoretical curves of Guyer and Zane[8] and Nosanow and Varma.[7] The relationship between T_N, θ, and the exchange energy J seems to be in some doubt; so we have used the most usual relation

$$\theta = 2T_N = zJ/2k$$

for the comparisons in Fig. 2, where z is the number of nearest neighbors for the body-centered cubic structure of the solid. Our values for T_N agree well with the ordering temperature deduced from compressional cooling.[23]

Although there is a slight possibility that even a He^4 impurity level of 1×10^{-5} could affect our results, all previous measurements[10,13,17,18,20] have indicated that He^4 impurities do not affect the results at low densities (i.e., $v \gtrsim 23.0$ cm^3/mole). We believe the antiferromagnetic Curie-Weiss constant we have measured to be repre-

sentative of pure solid He[3].

These measurements will be extended to lower temperatures and higher densities in the near future. We would like to acknowledge the assistance of Mr. L. A. Dietz in taking and analyzing the data.

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POSITRON ANNIHILATION AND ELECTRONIC LATTICE STRUCTURE IN INSULATOR CRYSTALS*

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The dimensions of the electronic lattice structure of the hexagonal quartz crystal and the fcc CaF_2 crystal have been measured by resolving characteristic markings on the angular-correlation curves as observed for the two gamma quanta emitted in the annihilation of positrons with electrons in these crystals.

The angular correlation of the two gamma quanta emitted in the para-annihilation of positrons with electrons in matter is observed in most experiments as the correlation function

$$I(p) = 2\pi \int_p^\infty \rho(\vec{p}') \, p' dp'. \tag{1}$$

The momentum p of the annihilating positron-electron pair in some laboratory direction is equal to $mc\theta$, where θ is the angle between the two emerging gamma quanta. In a crystal with any basis, the density $\rho(\vec{p})$ can be expressed in terms of the square of the Fourier-transformed positron-electron wave function in the unit cell $\rho_{\vec{k}_-}{}^c(\vec{p})$, where $\vec{k}_-$ is the wave vector of the annihilating electrons.[1] For thermalized positrons $(\vec{k}_+ \simeq 0)$

$$\rho(\vec{p}) = \sum_{\vec{k}} \delta_{\vec{p}, \vec{k}_-} + \vec{k} \rho_{\vec{k}_-}{}^c(\vec{p}). \tag{2}$$

The sum extends over all reciprocal lattice vectors $\vec{K}$. Equation (1) can then be factorized[2]:

$$I(p) = A(p)F(p). \tag{3}$$

$F(p)$ is determined by the momentum-density dis-