COMMENTS AND ADDENDA

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Antiferromagnetic Exchange Interaction in Solid He^3 †

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A previously unpublished analysis of nuclear-magnetic-susceptibility data on high-molar-volume bcc solid He^3 obtained by Anderson, Reese, and Wheatley shows that nuclear antiferromagnetism is to be expected in the ordered solid at low enough temperatures.

In work recently published by Pipes and Fairbank,[1] by Kirk, Osgood, and Garber,[2] and by Sites, Osheroff, Richardson, and Lee[3] the sign (and magnitude) of the exchange interaction in high-molar-volume bcc solid He^3 has been determined by measurements of nuclear magnetic susceptibility. The result is that a state of nuclear antiferromagnetism is to be expected at low enough temperatures. As noted in Refs. 2 and 3, the above work confirmed the results of an analysis we made[4] of measurements on the high-molar-volume solid performed by Anderson, Reese, and Wheatley.[5] In view of the interest in the subject and the importance of independent determinations of the sign of the interaction, we present the analysis of the data of Ref. 5 as reported in Ref. 4.

The data in question are those in Fig. 1 of Ref. 5 and labeled "35 atm, solid". The 35 atm refers to the pressure applied to the He^3 cell when the solid was being formed. There was considerable plug slippage in the formation of the solid. The resultant solid molar volume is somewhat in excess of 24.0 cm^3/mole, but the exact molar volume is not known. However, for purposes of determining the *sign* of the interaction, some uncertainty in molar volume is not serious. The He^3 contained about 30 ppm He^4, but this impurity should not affect our conclusions,[1] since the measurements were for high molar volumes.

Experimental results are shown in Fig. 1 in the form of the reciprocal of the nuclear magnetic susceptibility plotted against the magnetic temperature of a right circular cylinder (with diameter equal to height) of powdered cerium magnesium

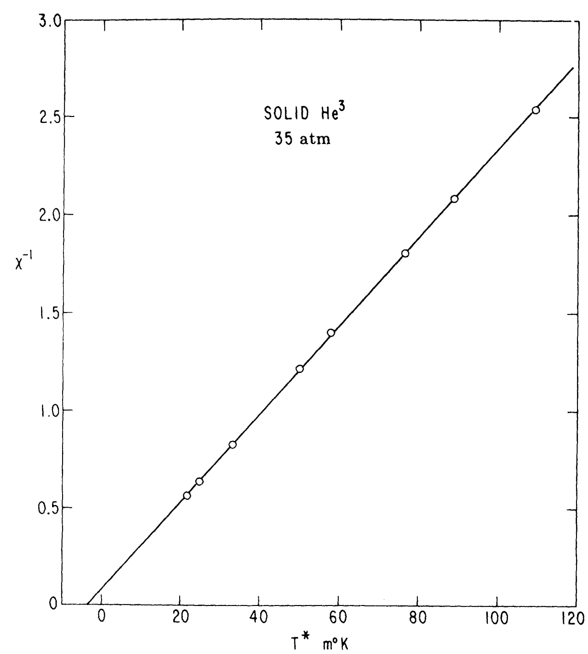

FIG. 1. Reciprocal of the nuclear magnetic susceptibility (arbitrary normalization) plotted as a function of the magnetic temperature of powdered CMN. The data are from Ref. 5. The straight line shown is a least-squares fit to Eq. (3).

nitrate (CMN). Data extend over the range 22–110 m°K.

Assuming an effective spin Hamiltonian

$$\mathcal{H} = -J \sum_{\{ij\}} \vec{I}_i \cdot \vec{I}_j \ , \qquad (1)$$

a bcc lattice, and nearest-neighbor interactions only, the susceptibility χ is expected[6] to be given by

$$\chi = (C/T)[1 - \theta/T + \tfrac{3}{4}(\theta/T)^2 + \cdots] \ , \qquad (2)$$

where C is the Curie constant and $\theta \equiv -2\, J/k$, k being Boltzmann's constant.

At high enough temperatures, one has

$$C/\chi \simeq T + \theta \ . \qquad (3)$$

The straight line shown on Fig. 1 is a fit of the data to this equation, in which case we find $\theta = +(3.5 \pm 0.4)$ m°K. The data are somewhat better fitted by the expression

$$\chi T = C\,[1 - a(1/T) + b(1/T)^2] \qquad (4)$$

obtained from Eq. (2) with $a = \theta$ and $b = \frac{3}{4}\theta^2$. The fit gives

$$a = \theta = +(4.6 \pm 0.2) \text{ m°K and } b = (35.2 \pm 12.7) \text{ m °K}^2 = \tfrac{3}{4}((6.9 \pm 1.3) \text{ m °K})^2 \ ,$$

where the indicated errors represent the rms deviation of $\chi T^2/C$ for a and $\chi T^3/C$ for b. Since these rms deviations represent only the relationship of the data to a smooth curve they no doubt do not correctly assess the accuracy of the value of θ for the solid He^3 sample. The above values of $|\theta|$ are somewhat greater than the value of 2.9 m°K expected for a molar volume of 24.1 cm^3/mole from measurements of $(\partial P/\partial T)_V$ by Panczyk, Scribner, Straty, and Adams.[7] However, the determination of the sign of θ to be positive appears to be definitive. Thus at low enough temperatures a state of nuclear antiferromagnetism is to be expected in the solid.

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Fine Structure of the 2^3P, 3^3P, and 4^3P States of Li^+

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The fine structure of the 2^3P, 3^3P, and 4^3P states of Li^+ has been computed, and the results are given in a table.

In view of experiments which are being planned to measure the fine structure of the triplet levels of Li^+, we have computed theoretical values for the fine-structure splitting of the 2^3P, 3^3P, and 4^3P levels of the Li^7 positive ion. The methods used in the calculation are basically the same as those which were employed for the case of helium,[1] and the results are given in Table I. The factor $\alpha^2 R_{Li^7} = 5.843099$ has been used in converting to cm^{-1}, and the values in the table are estimated to be subject to an error of not more than ±1 in the last figure quoted. This estimate of the error