Measurement of the Spin Dependence of the $He^3(n,p)T$ Reaction and of the Nuclear Susceptibility of Adsorbed He^3 †

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The spin dependence of the $He^3(n,p)T$ reaction was investigated by studying the transmission of polarized thermal neutrons through a polarized He^3 target which consisted of He^3 adsorbed on zeolite. It was found that the interaction cross section was essentially all associated with an $I-\frac{1}{2}=0$ channel, i.e., $\sigma_{I-1/2}/\sigma_0=1.010 \pm 0.032$. Once the spin dependence of the cross section was established, polarized neutrons provided a convenient method of studying the nuclear spin susceptibility of He^3. Susceptibility measurements were made on our adsorbed-phase target over the temperature range 0.06–1.0°K. It was found that the nuclear susceptibility began to fall below Curie's law at about 0.2°K, indicating the onset of some type of antiparallel ordering in the nuclear spin system.

I. INTRODUCTION

INTEREST in the four-nucleon system has recently been given considerable impetus by the discovery of excited states of the alpha particle. Evidence of these states has been observed in many reactions in which He^4 is formed as a compound system. At present a resonance with a width of about 0.2 MeV is known to exist at 20.1 MeV above the ground state, and there are others at 22.5 and 26 MeV.[1,2]

Cluster-model calculations made by Szydlik and Werntz[3] indicate that the lowest energy resonance is associated with a $J^\pi=0^+$, $T=0$ state. Werntz[4] has also shown that a 0^+ resonance at about 20.4 MeV will account for both the thermal $He^3(n,n)$ and $He^3(n,p)T$ cross sections and the low-energy elastic p-T cross section. Further, Meyerhof has assumed this spin and parity in his analysis[1] of $He^3(D,p,p)T$ reaction data, and it is also consistent with the recent angular-distribution measurements of Cerny, Détraz, and Pehl.[5] Thus there are persuasive arguments which suggest that the low-energy $He^3(n,p)T$ interaction is associated with the 20.1-MeV excited state of He^4, which lies only 0.5 MeV below the neutron binding energy. There is also some indirect experimental evidence that this is the case: Bergman and Shapiro[6] have found that the cross section departs from $1/v$ dependence in a way consistent with the interaction proceeding via a 0^+ state lying below the neutron binding energy.

A direct way to examine this question is to look for spin dependence in the neutron-He^3 cross section. By studying the transmission of polarized neutrons through polarized He^3 nuclei, it is possible to determine unambiguously the separate contributions of the 0^+ and 1^+ spin states to the cross section.

If, as expected, the thermal-neutron–He^3 interaction is strongly spin-dependent, then polarized neutrons can be used to examine nuclear spin ordering in He^3. This is a subject which has attracted considerable interest in recent years, and both the liquid and solid states have been extensively studied. Liquid He^3 can be described as having the characteristics of a system of fermions. This implies that as the temperature decreases the nuclear spins line up antiparallel, the nuclear susceptibility becoming relatively independent of the temperature below 0.1°K.[7] In the solid phase the susceptibility follows Curie's law down to at least 0.05°K, showing no evidence of the effects of Fermi-Dirac statistics.[8–10] An exchange interaction is observed, but it is of the order of tenths of millidegrees. Bernardes and Primakoff,[11] who developed the first theory of solid He^3, predicted an antiferromagnetic exchange interaction between nuclear spins which would decrease with increasing density and finally become ferromagnetic at very high densities. Later, their calculation of the exchange interaction was revised by Saunders[12] and Nosanow,[13] and the modified theory gives results in reasonable quantitative agreement with experiment.

While notable progress has been made on the solid and liquid phases, there is very little information available at present on the properties of the adsorbed phase. It is known from measurements of adsorption isotherms,[14] however, that the density is appreciably higher in the adsorbed phase than in the solid phase. Since spin ordering is very sensitive to the interatomic spacing, there has been speculation that adsorbed He^3

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might differ considerably in its ordering properties from either the liquid or the solid. There does not as yet, however, appear to be any conclusive experimental evidence of spin ordering in the adsorbed phase, at least down to 0.5°K.[15] Peaks have been observed in heat-capacity measurements[16] made below 1°K, but they are thought to be associated with either gas desorption or a surface-phase transition[17] rather than nuclear spin ordering.

This paper describes a study of the spin dependence of the He$^3(n,p)$T interaction made with polarized thermal neutrons. Our measurements showed that the cross section is essentially entirely associated with a 0^+ state of He^4. In addition, we also investigated the possible application of polarized neutrons to the study of the nuclear spin susceptibility of He^3. Using our adsorbed-phase He^3 target, we found that measurements of very reasonable accuracy could be made with this technique. In fact, the measurements showed that the susceptibility of adsorbed He^3 falls significantly below Curie's law at about 0.2°K, indicative of the onset of some type of antiparallel ordering in the nuclear spin system. Unfortunately, the properties of the adsorbed phase in zeolites are not well understood, and interpretation of the data is therefore rather speculative at this time. Nevertheless, the results are sufficient to demonstrate the potential value of polarized neutrons in studying spin ordering in He^3.

II. THEORY OF THE MEASUREMENTS

A. The Cross Section

The problem of polarized thermal neutrons interacting with polarized nuclei has been treated by Rose[18] who showed that the interaction cross section can be expressed as

$$\sigma=\frac{I}{2I+1}(1-f_Nf_n)\sigma_-+\frac{I+1}{2I+1}\left(1+\frac{I}{I+1}f_Nf_n\right)\sigma_+. \quad (1)$$

In this formula f_n and f_N are the neutron and nuclear polarizations and σ_- and σ_+ are the cross sections for interaction in the states $J=I-\frac{1}{2}$ and $J=I+\frac{1}{2}$, respectively. It will be advantageous to separate this expression into polarization-independent and polarization-dependent terms thus:

$$\sigma=\sigma_0+f_Nf_n\sigma_p\,, \quad (2)$$

where

$$\sigma_0=\frac{I+1}{2I+1}\sigma_++\frac{I}{2I+1}\sigma_-=\sigma_{I+1/2}+\sigma_{I-1/2} \quad (3)$$

and

$$\sigma_p=\frac{I}{2I+1}(\sigma_+-\sigma_-)=\frac{I}{I+1}\sigma_{I+1/2}-\sigma_{I-1/2}. \quad (4)$$

B. The Transmission Effect

In general, when a polarized beam passes through a polarized sample, neutrons interact in both the $J=I-\frac{1}{2}$ and $I+\frac{1}{2}$ states of the compound system. Expression (2) shows that the cross section will differ depending on the direction (i.e., the sign) of f_n. Thus the transmission $\mathcal{T}_p$ through the polarized sample when the neutron beam is polarized parallel to the applied magnetic field H will be different from the transmission $\mathcal{T}_a$ when it is polarized antiparallel to H. To express this conveniently we define the transmission effect

$$\mathcal{E}\equiv(\mathcal{T}_p-\mathcal{T}_a)/(\mathcal{T}_p+\mathcal{T}_a)\,, \quad (5)$$

which can be shown to be related to σ_p, the polarization-dependent part of the cross section, by the expression[19]

$$\mathcal{E}=-\tfrac{1}{2}(1+\varphi)f_n\tanh(N\sigma_pf_Nt)\,. \quad (6)$$

Of the terms not already defined, φ is the efficiency for reversing the neutron polarization, N is the number of target nuclei per cm^3, and t is the thickness of the sample. Since $N\sigma_pf_Nt\ll1$, it is a sufficiently good approximation to write

$$\mathcal{E}=-\tfrac{1}{2}(1+\varphi)f_n(\sigma_p/\sigma_0)f_NN\sigma_0t\,. \quad (7)$$

$(1+\varphi)f_n/2$ is a quantity which can be independently determined, and $N\sigma_0t$ is evaluated by simply measuring the transmission of neutrons through the unpolarized sample. Combining these quantities with the measured value of $\mathcal{E}$ thus determines the product $(\sigma_p/\sigma_0)f_N$.

In the absence of any hyperfine interaction, the nuclear polarization f_N is related to the nuclear spin susceptibility by the expression $\chi=\mu f_N/H$, where μ is the nuclear magnetic moment. Thus the transmission effect measurement also determines the product

$$(\sigma_p/\sigma_0)\chi=-\frac{2\mathcal{E}\mu}{(1+\varphi)f_nN\sigma_0tH}. \quad (8)$$

Note that the right-hand side contains only experimentally determined quantities.

III. DESCRIPTION OF THE EXPERIMENT

A. Polarized-Neutron Spectrometer and Cryostat

In brief, the apparatus used to make the measurements consists of a polarized-neutron crystal spectrometer with an adiabatic demagnetization cryostat mounted on the spectrometer arm. Nuclear polarization is produced by cooling the samples to very low temperatures in a magnetic field of up to 15 kOe. We will not

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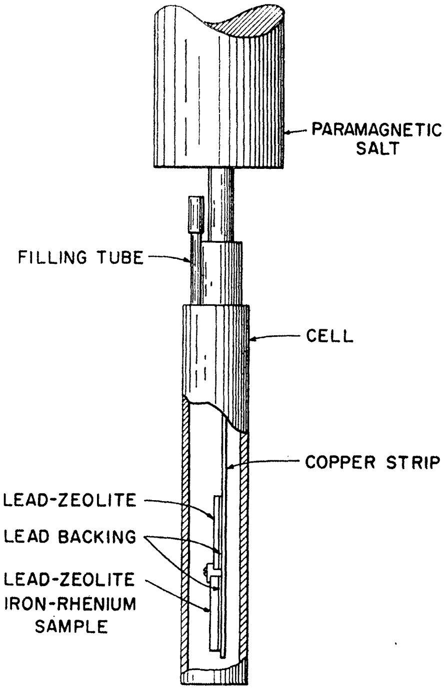

FIG. 1. Cutaway view of sample cell, showing the arrangement of the lead-zeolite and lead-zeolite plus Re-Fe alloy samples within the vacuum-tight container.

attempt to describe here either the cryostat or the neutron monochromating and polarizing systems since details of the design are already available elsewhere.[19] We will only mention in passing that the cryostat has certain special features to bring the polarized-neutron beam through the low-temperature space and to provide a very large refrigerating capacity. Targets are routinely kept below 0.1°K for periods of 8 h or more since long counting times are required to measure the transmission effect with the necessary statistical accuracy.

B. The Absorbed He^3 Target

We selected the adsorbed phase of He^3 as a target primarily because of its intrinsic interest from the point of view of nuclear spin ordering. However, there were other considerations as well. For example, the nuclear spin relaxation rate in adsorbed He^3 is short.[20] Another advantage is that targets of very high density are easy to make and handle.

Since He^3 has no nuclear hyperfine interaction, the amount of polarization which can be produced in the paramagnetic state is determined simply by the ratio of μH to kT. With a field of only 15 kOe available it was clearly of paramount importance to obtain good thermal contact between the He^3 system and the refrigerating paramagnetic salt (iron ammonium alum). After considerable experimentation, we found that this could be done adequately by making the targets of a mixture of finely powdered zeolite adsorber and lead. The mixed powders (in the ratio 0.6 g 13x zeolite to 2.4 g lead) were placed in a die on top of a layer of 3.4 g of lead powder and then compacted at a pressure of 40 tons per square inch.[21] This produced a rigid slab with dimensions $0.76\times 1.01\times 0.085$ in. with a 0.025-in.-thick pure-lead surface layer. This layer was then soft soldered directly to a copper strip which was in turn connected to the paramagnetic salt.

We were particularly concerned about temperature gradients between the target and the salt, especially at temperatures below 0.1°K. To get an indication of the magnitude of such gradients we used nuclear polarization in Re^{185} as a thermometer. For this purpose we prepared a second target, identical to the first except for the addition of 5.6 g of Re$_{0.09}$Fe$_{0.91}$ alloy filings. Several of our runs were made with both targets attached to the copper strip.

Details of the arrangement of a typical target assembly are shown in Fig. 1. Both targets were contained within a vacuum-tight cylindrical cell 5.14 in. long and 0.875 in. in diameter. The copper strip to which the targets were attached passed through the top of the cell and connected to a nest of fine copper wires embedded in the lower paramagnetic salt (weight 220 g). Above this salt was another somewhat larger iron ammonium alum salt connected to it by a superconducting-lead heat switch. This guard salt was in turn connected to the liquid-helium bath by a second lead heat switch.

Filling the cell with He^3 gas was done in a separate operation. First the zeolite was outgassed by holding it in vacuum at approximately 250°C for 8 h. Then the cell was filled with gas. We used only enough He^3 to obtain roughly monolayer coverage, typically about 104 cm^3 (N.T.P.) to 0.6 g of 13x zeolite. The amount of gas adsorbed in the target was determined by measuring the change in its neutron transmission when loaded with He^3. In every case this equalled the amount of gas originally introduced into the cell.

C. Thermometry

Paramagnetic-salt temperatures were determined from ballistic-galvanometer measurements of the magnetic susceptibility of the salt. The observed susceptibility, after correction for the effect of the demagnetizing field, served to define a magnetic temperature T^* which had then to be converted to the thermodynamic temperature T. Unfortunately, there exist two T^*-versus-T scales for iron ammonium alum, and they are not in good agreement. The two scales are based on measurements made by Kurti and Simon[22] (KS) and Cook,

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[21] R. I. Schermer and L. Passell, Rev. Sci. Instr. **36**, 709 (1965).

[22] Tabulated in *American Institute of Physics Handbook*, edited by Dwight Gray (McGraw-Hill Book Company, Inc., New York, 1957), 1st ed., Sec. 4, p. 18.

Meyer, and Wolf[23] (CMW). For a given value of T_* the KS data give values of T which are 10% higher than those of CMW at 0.2°K and 20% higher at 0.05°K. We preferred the more recent CMW scale for two reasons. First, it appeared to be *a priori* more accurate, because of the use of a seemingly more refined experimental technique. Second, using the KS scale above 0.15°K led to values of σ_p/σ_0 greater than unity, which, in view of the definition of these terms, implies that some systematic error must be present. It should be emphasized, however, that the CMW scale could also be in error, and if so, both the value of σ_p/σ_0 and the temperature dependence of the susceptibility as determined from our data will be directly affected.

Setting aside the question of systematic error in the T^*-versus-T scale, there would normally remain the difficulty of accurately determining the demagnetizing field correction which converts the susceptibility of the cylindrical salt to that of an equivalent sphere. While the "shape correction" is not of great importance at temperatures above ~0.1°K, it becomes increasingly critical at lower temperatures. Fortunately, using the polarization of Re^{185} in the Re-Fe alloy to define the temperature scale at low temperatures almost completely circumvents this problem.

The procedure followed was to calibrate the transmission effect at 2.16 eV in Re^{185} over the temperature range 0.15 to 0.95°K against the paramagnetic salt temperature as defined by the CMW scale. This was done in a separate experiment using a Re-Fe slab in good thermal contact with the salt. Since the Re^{185} polarization is accurately given by the Brillouin function, $B_{5/2}(A/kT)$ (A is the magnetic nuclear hyperfine coupling constant), we have $\mathcal{E}=CB_{5/2}(A/kT)$. The constant C includes the neutron beam polarization and the value of σ_p/σ_0 for Re^{185} at 2.16 eV, which are known, and the effective value of σ_0 averaged over the finite energy spread in the beam and including the effects of Doppler broadening of the resonance, which can be calculated.[24] From the measured values of $\mathcal{E}$ we obtained $A/k = -0.028$°K, in good agreement with that reported by Stolovy[25] for the identical alloy.

Having found A, we then used the observed transmission effect in the Re-Fe alloy to measure the temperature of the target below 0.15°K. Unfortunately, in the calibration range above 0.15°K, $A \ll kT$ and $\mathcal{E} \rightarrow 7CA/6kT$. Thus only the product CA is determined. At low temperatures, however, values for both C and A are required. There is some possibility of error involved in separating CA into its components. However, since $CB_{5/2}(A/kT)$ falls only slightly below $7CA/6kT$, even at the lowest temperatures, this cannot lead to any significant distortion of the temperature scale. The most important source of error is simply the statistical uncertainty in the calibration procedure which, we estimate, results in a ±3% systematic uncertainty in our T-T^* relation. It is interesting that the resulting Re-Fe temperature scale deviates smoothly from the CMW scale as the temperature decreases and finally coincides with the KS scale at the lowest temperatures.

By monitoring the Re^{185} polarization in the Re-Fe alloy filings with polarized neutrons, we were able to directly measure the temperature of the lead-zeolite matrix which formed the adsorbed He^3 target. It was found that even at the lowest temperatures the target matrix reached equilibrium with the paramagnetic salt in less than 15 min. There remained the possibility that the adsorbed He^3 was in poor thermal contact with the lead-zeolite matrix. If this were the case, however, a gradual increase in the He^3 nuclear polarization should have occurred following adiabatic demagnetization. In fact, no evidence of any such relaxation process was observed.

In operation we could not monitor the Re^{185} polarization at the same time that we made measurements on He^3. Consequently, it was necessary to use the paramagnetic salt susceptibility as a monitor of the target temperature while the measurements were in process. Because of random errors in calibration in the liquid-helium range, our T^* measurements were not reproducible to better than about 3% from run to run. This was an important limitation on the reproducibility of the data.

D. Transmission-Effect Measurements

Polarized 0.115-eV neutrons were used for all measurements on adsorbed He^3. The beam polarization was 83% at this energy. It was selected because it gave a high polarized-neutron intensity and because the second-order contamination could be conveniently removed with a europium metal filter (0.012 in. thick). Transmission effect measurements were made at 14.7 and 8.95 kOe at various temperatures between 0.05°K, the lowest temperature which could be reached by adiabatic demagnetization, and 0.95°K, the temperature of the pumped liquid-helium bath. For measurements at intermediate temperatures the lower salt was magnetized in less than the full magnetic field available, while the upper salt was magnetized at the maximum field. Thus after demagnetization the lower salt was insulated from the major sources of heat by the very cold upper salt and its warmup rate was substantially reduced.

Altogether, three complete runs were made. For the first run we used 99.5% isotopic purity He^3 gas contained in a copper cell. Because of suspected eddy current heating in the cell wall we repeated this measurement with a brass cell. Finally, we repeated the second run with gas of 99.98% isotopic purity.[26] In this

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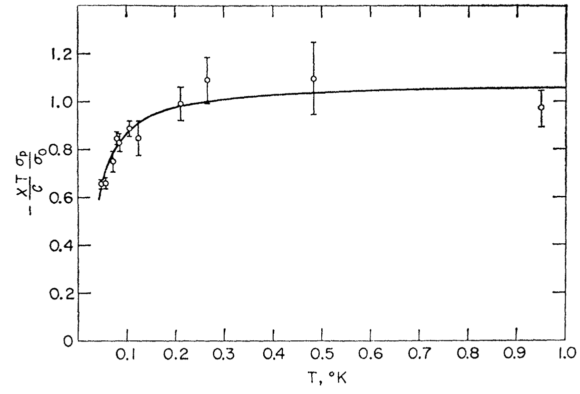

FIG. 2. $(\sigma_p/\sigma_0)\chi T/\mathcal{C}$ as a function of absolute temperature T. The ordinate is given in Eq. (8) in terms of directly measured quantities. Points are experimental values. The solid line is the best fit to the data using a two-term inverse-temperature expansion for the susceptibility. Curie's law would be a horizontal line on this plot.

run we also replaced the target containing Fe-Re alloy with a target in which approximately 60% of the sodium in the 13x zeolite was replaced by cobalt. While this "cobalt" zeolite was appreciably less efficient as an absorber, the results of the transmission effect measurements made with it showed no significant difference from the previous measurements.

To confirm that the observed effects were due to He^3 alone, we repeated the first run with He^4 in the cell. No transmission effect was observed even at the lowest temperatures.

In Fig. 2 we show the observed temperature dependence of the product $(\sigma_p/\sigma_0)\chi T/\mathcal{C}$. As is customary, the results are expressed in terms of the Curie constant, $\mathcal{C}=\mu^2(I+1)/3Ik$. Only the data from the last run using the highest purity gas are shown since they are representative of all the results. The error bars indicate the standard deviation due to counting statistics only. This varied from a few percent at the lowest temperatures to over 10% above 0.25°K, with the exception of the point at 0.95°K which was better determined.

IV. DATA ANALYSIS

Since the thermodynamic properties of the adsorbed phase are not well understood, interpretation of the data in terms of existing models of either the liquid or solid will be at best a doubtful procedure. Fortunately, to determine σ_p/σ_0 it is only necessary to establish that the nuclear spin system is well above its ordering temperature, because the susceptibility of a paramagnetic system is a known quantity. Once χ is known, substitution into Eq. (8) gives σ_p/σ_0 in terms of $\mathcal{E}$ and the other known parameters. It should perhaps be pointed out that σ_p/σ_0 can be determined simply from the measurements at 1°K. If we had no other experimental objectives in mind, the data at lower temperatures would only be necessary to demonstrate that the deviation from Curie's law at 1°K is very small. We found, as expected, that any reasonable model used to describe the susceptibility of adsorbed He^3, provided it approaches Curie's law in the high-temperature limit, will give the same value for σ_p/σ_0.

It is evident in Fig. 2 that the susceptibility of the adsorbed phase falls below Curie's law at low temperatures. Some kind of spin ordering is clearly taking place. This must be a result of either the effect of Fermi-Dirac statistics or an exchange interaction between nuclear spins or possibly both. We have tried two extreme models to describe the data, one representing a magnetic system in the neighborhood of its ordering temperature and the other a system of fermions in the neighborhood of its degeneracy temperature.

If we consider adsorbed He^3 as a purely magnetic system it is natural to try a Curie-Weiss law, $\chi=\mathcal{C}/(T+\Delta)$. Unfortunately, an expression of this form inserted into Eq. (8) does not give us a completely satisfactory weighted, least-squares fit to the data. The constants σ_p/σ_0 and Δ shift systematically as the low-temperature data are discarded. This type of deviation is not unusual when magnetic susceptibilities are measured in the region of the Néel temperature. A more complete expression for the susceptibility has been given by Van Vleck[27] as a series in inverse powers of T

$$\chi=\sum_{n=1}^{\infty} a_n T^{-n},$$

where the constants a_n depend upon the exchange interaction and the structure of the material. The Curie-Weiss law is then the (1,1) Padé approximant to this series.

We found that it was only necessary to use the first two terms of the Van Vleck series in the form

$$\chi=(\mathcal{C}/T)(1-\theta/T) \tag{9}$$

to get a satisfactory weighted least-squares fit over the entire temperature range. Adding a third $1/T^3$ term did not make any significant improvement. Furthermore, there was no indication of any systematic variation in the constants σ_p/σ_0 and θ when the low-temperature data were discarded. The least-squares fit to the last set of measurements is shown as the solid line in Fig. 2.

The results for each of the individual runs are listed in Table I, where the standard deviations are compounded from counting statistics, the uncertainties in

TABLE I. Results for individual runs.

Run	Applied field (kOe)	σ_p/σ_0	θ (10^{-3} °K)
Ia	14.7	0.962±0.093	17±10
Ib	8.95	0.85 ±0.11	8± 8
IIa	14.7	0.971±0.047	19± 3.0
IIb	8.95	1.038±0.056	26± 2.8
III	14.7	1.080±0.045	19± 1.6

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[27] J. H. Van Vleck, J. Chem. Phys. 5, 320 (1937).

$f_n(1+\varphi)/2$, $Nl\sigma_0$, and H, and the 3% uncertainty in the T^* scale frum run to run. The weighted average values are

$$\sigma_p/\sigma_0=-1.013\pm0.042\,,$$
$$\theta=0.0201\pm0.0016°\mathrm{K}.$$

The errors include the 3% uncertainty in the T^*-T relation. A more physically meaningful quantity than σ_p/σ_0 is $\sigma_{I-1/2}/\sigma_0$, which is related to it by formulas (3) and (4). Using the above value of σ_p/σ_0, we find

$$\sigma_{I-1/2}/\sigma_0=1.010\pm0.032\,.$$

At the other extreme we have also considered whether a Fermi gas model could be used to describe the data, as has been attempted with liquid He^3. The apparent degeneracy temperature T_0 is not determined by the density but rather is treated as a free parameter. Although the Fermi-Dirac functions are tabulated,[28] the least-squares fitting is tedious. We, therefore, only fitted the data shown in Fig. 2, which is typical of all our results. The best, weighted least-squares fit occurs with $T_0=0.092\pm0.005°\mathrm{K}$ and $\sigma_p/\sigma_0=1.06\pm0.05$. This is the same as the value obtained for the data in Fig. 2 by using the Van Vleck series and given in Table I. Furthermore, on the scale of Fig. 2 the curves for these two different models are almost indistinguishable.

V. DISCUSSION

We have determined that the fraction of the cross section in the $I-\frac{1}{2}$ channel is 1.010±0.032, i.e., the thermal $He^3(n,p)T$ cross section is essentially all associated with a 0^+ state (or states) of the compound system. Any possible 1^+ contribution to the cross section lies within the 3% experimental uncertainty. As was described in the Introduction, this is exactly what would be expected on the basis of the current experimental and theoretical results on excited states of He^4.

On the other hand, the observed departure of the nuclear susceptibility of adsorbed He^3 from Curie's law is unexpected. Let us consider briefly why this is so.

In a general way it can be said that while the susceptibility of liquid He^3 is strongly affected by Fermi-Dirac statistics, the susceptibility of solid He^3 is not. This is a result of the fact that the atoms in the solid are well localized, and their momenta are correspondingly poorly defined. The ordering in momentum space associated with Fermi-Dirac statistics is, in effect, obliterated by the frequent collisions with neighbors which preserve the localization of the atoms. Ordering can therefore occur in the solid only through the medium of the very small exchange interaction between nuclear spins.

Since the density of the first adsorbed monolayer is very great, its suceptibility might be thought to be like that of a very high density solid. Understandably, experiments on the solid phase have never been performed at anything approaching the density of the first adsorbed monolayer. However, within the range of the measurements the exchange interaction decreases with increasing density.[10] We might thus expect that a very high-density solid would have an extremely small ($<10^{-4}$ °K) antiferromagnetic—or possibly even a ferromagnetic—exchange interaction.[11–13] If we attempt to interpret our data in terms of an exchange interaction, however, we obtain an antiferromagnetic Weiss constant θ of about 0.02°K. Evidence of antiferromagnetism in the nuclear spin system thus appears at surprisingly high temperatures.

There are several possible explanations which come to mind. First, it is conceivable that the adsorbed monolayer, although strongly bound to the wall, retains sufficient mobility along the wall to show a liquid-like susceptibility. A more likely possibility is that the first monolayer does have the properties of a high-density solid but subsequent layers become more and more liquid-like. We used 104 cm^3 (N.T.P.) He^3 gas adsorbed on 0.6 g of 13x zeolite. Although there do not appear to be any adsorption isotherms available for He^3 on zeolite, it was thought that at this concentration the adsorbed film would be essentially a monolayer. It is not implausible, however, that some of the gas was present as a second layer. In this case, the susceptibility would be the weighted sum of the solid-like and liquid-like susceptibilities of the two layers. We estimate that roughly 20% of the He^3 in our adsorbed-phase target would have to be present as liquid of normal density in order to account for the observed susceptibility.

In view of these results, it would clearly be of interest to study the susceptibility of the adsorbed phase as a function of coverage. This should establish whether the first monolayer or only the subsequent layers have liquid-like properties. Unfortunately, it was not possible to do this with the sealed gas cell used for our target. Further study of the adsorbed phase with a system of improved flexibility is now being planned.

ACKNOWLEDGMENTS

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[28] J. MacDougall and E. C. Stoner, Phil. Trans. Roy. Soc. (London) **A237**, 67 (1939).