$Ti^{46}(He^3,d)V^{47}$ Reaction*

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A high-resolution study of the $Ti^{46}(He^3,d)V^{47}$ reaction has been made at a bombarding energy of 16.5 MeV. Fifty-three states were observed in V^{47} up to an excitation energy of 7 MeV, and deuteron angular distributions were measured between 7° and 60°. Orbital-angular-momentum transfers and spectroscopic factors have been evaluated for the more intense transitions with the aid of distorted-wave Born-approximation analysis. Of particular interest is the "anomalous" $\frac{3}{2}^-$ assignment for the ground state of V^{47}. Other new spin-parity assignments for low-lying states in V^{47} are the following: 0.089 MeV, $\frac{5}{2}^-$; 0.147 MeV, $\frac{7}{2}^-$; 0.260 MeV, $\frac{3}{2}^+$, and 1.664 MeV, $\frac{1}{2}^+$. The analog state to the 0.160-MeV ($\frac{7}{2}^-$) level in Ti^{47} was located at 4.30-MeV excitation energy, which corresponds to a Coulomb displacement energy of $\Delta E_c = 7.84 \pm 0.02$ MeV for the V^{47}-Ti^{47} isobaric pair. Evidence for possible deformation in V^{47} is discussed.

I. INTRODUCTION

Of those nuclei in the $1f_{7/2}$ shell which are readily accessible to experimental investigation, V^{47} is one of the least well studied. Thus, although energy levels up to about 3-MeV excitation in V^{47} have been observed by means of the $Cr^{50}(p,\alpha)$,[1] $Ti^{46}(p,\gamma)$[2] and $Ti^{47}(p,n)$[3] reactions, no spin-parity assignments have been made. In particular, the assumed $\frac{5}{2}^-$ character for the ground state[4] has been based mainly on its observed β^+-decay.

On the other hand, there are extensive theoretical predictions concerning the properties of the low-lying levels of V^{47}, as well as many other nuclei in the $1f_{7/2}$ shell. For example, within the framework of a pure $1f_{7/2}$ shell-model configuration, McCullen, Bayman, and Zamick[5] and Ginocchio[6] have successfully reproduced the excitation energies of the low-lying $\frac{7}{2}^-$ and $\frac{5}{2}^-$ states in many odd-A nuclei. However, their calculations generally predict the $\frac{3}{2}^-$ states arising from this configuration to be as much as 1 MeV higher in excitation than their observed locations. In a more recent study, Malik and Scholz[7] have also shown that the level structures of a number of odd-A nuclei in the $1f_{7/2}$ shell can be rather well described in terms of the strong coupling rotator model with Coriolis coupling between bands. According to this model, the relative locations of the low-lying $\frac{7}{2}^-$, $\frac{5}{2}^-$, and $\frac{3}{2}^-$, states may provide a sensitive measure of the nuclear deformation and a brief report of the present study concerning these states has already been presented elsewhere.[8]

Considerable spectroscopic information on V^{47} may be obtained from a study of the $Ti^{46}(He^3,d)$ reaction. Thus, from measurements of the deuteron angular distributions and with the aid of distorted wave Born-approximation (DWBA) theory, it is possible in many cases to extract unambigous values of the transferred proton orbital angular momenta which determine the parities of the final states. Spectroscopic factors for the various transitions may also be readily extracted, together with close limits on the final state spin values.

Of further interest here are the locations of the $T=\frac{3}{2}$ states in V^{47} which are analogs of the low-lying states of Ti^{47}. In view of the small neutron excess the $T=\frac{3}{2}$ states are expected to be bound and the (He^3,d) reaction is one of the few convenient reactions by which they may be studied. In cases such as this, where the analog states occur at rather low excitation energies, they also share an appreciable part of the total single-particle transition strength.

II. EXPERIMENTAL PROCEDURE

A thin self-supporting target of Ti^{46} was bombarded with 16.5-MeV $He^{3\,2+}$ ions from the University of Pennsylvania tandem accelerator. Deuteron spectra were recorded on Ilford K2 nuclear emulsion plates using a 65-cm-radius broad-range magnetic spectrograph, and angular distributions of the deuterons were measured between 7° and 60°. Recent improvements[9] of the accelerator injector system for He^3 acceleration enabled a beam current on target of 0.20 μA to be obtained over a rectangular area 2 mm×0.5 mm. The total charge collection per exposure was 1500 μC.

The target was prepared by evaporation from a tantalum boat of titanium metal enriched to 85% in Ti^{46}. The target thickness was later measured by direct weighing and found to be 75 $\mu g/cm^2$, with an estimated uncertainty of 30% due mainly to the presence of tantalum in the target. The other principal contaminant was Ti^{48} which, therefore, also gave rise to deuteron groups leading to levels in V^{49}. However, a previous study of the $Ti^{48}(He^3,d)V^{49}$ reaction in this laboratory[10]

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† On leave of absence from the Department of Physics, Technion–Israel Institute of Technology, Haifa, Israel.
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5 J. D. McCullen, B. F. Bayman, and L. Zamick, Phys. Rev. **134**, B515 (1964).
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7 F. B. Malik and W. Scholz, Phys. Rev. **150**, 919 (1966).
8 B. Rosner and D. J. Pullen, Phys. Rev. Letters **18**, 13 (1967).
9 C. H. Holdrow and R. Middleton, Bull. Am. Phys. Soc. **11**, 360 (1966).
10 D. J. Pullen, Baruch Rosner, and Ole Hansen, Phys. Rev. (to be published).

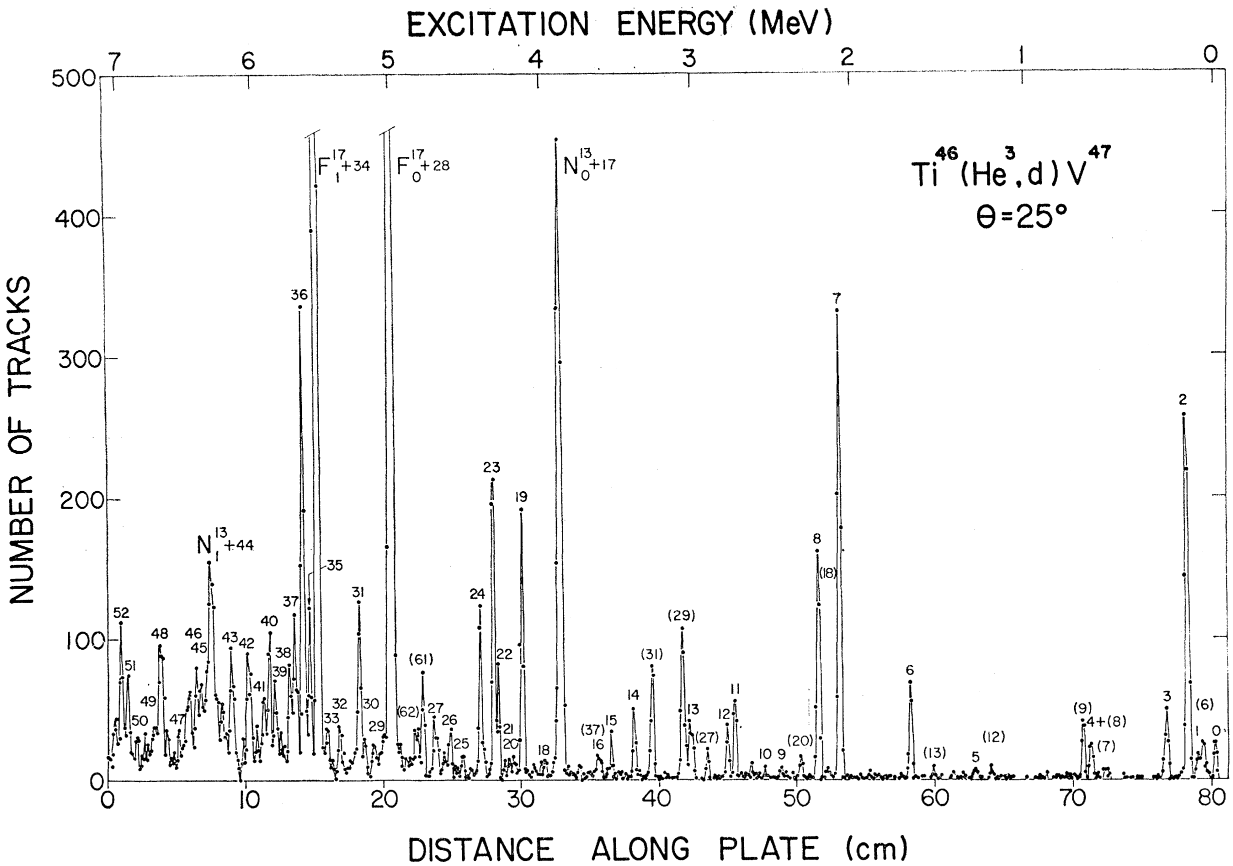

FIG. 1. Deuteron spectrum obtained from the $Ti^{46}(He^3,d)V^{47}$ reaction, measured at a bombarding energy of 16.5 MeV and a laboratory angle of 25°. Groups shown without parentheses correspond to levels in V^{47} and those in parentheses to levels in V^{49} (Ref. 10), the latter being due to approximately 13% of Ti^{48} in the target.

enabled the contaminant deuteron groups to be readily identified in the present work. This identification was also facilitated by using the same magnetic field of 10 890 g for both reaction studies.

III. RESULTS AND DISCUSSION

A. Level Excitation Energies and Angular Distributions

A deuteron spectrum from the $Ti^{46}(He^3,d)V^{47}$ reaction measured at 25° is shown in Fig. 1. The over all energy resolution is better than 20 keV. Groups corresponding to states in V^{47} are labeled numerically without parentheses and, in all, 52 excited states have been identified up to an excitation energy of about 7 MeV. In addition to the contaminant deuteron groups corresponding to levels in V^{49} (shown in parentheses), several intense groups arising from C^{12} and O^{16} in the target are also seen. These could be readily identified by their characteristic energy change with angle and did not generally interfere at more than one angle with any single deuteron group originating from the $Ti^{46}(He^3,d)V^{47}$ reaction.

Angular distributions were obtained for the more strongly excited states and these are shown in Fig. 2 ($l_p=1$) and Fig. 3 ($l_p=0$, 2, and 3). For ease of presentation, the cross-section units have been made arbitrary. The full-line curves are the results of DWBA calculations which were carried out by Dr. R. H. Bassel at Brookhaven National Laboratory using the code JULIE. These calculations were made using a Saxon-Woods potential for the bound state and incident and outgoing channels. Spin-orbit coupling terms were employed in the bound state and elastic deuteron channel only and the distributions were evaluated with a radial cutoff at 4.1 fm. For Q values less than -5.5 MeV, which corresponds to the He^3 breakup energy, no DWBA calculations are available. Dashed lines have thus been drawn through those distributions which fall into this category, and these are meant to serve only as a guide to the eye.

A summary of the experimental results is presented in Table I. Column 2 lists the level excitation energies observed in the present work and the energies given in column 3 are the values obtained by Brown *et al.*[1] from a study of the $Cr^{50}(p,\alpha)V^{47}$ reaction. The levels reported in their study at 1.148, 1.306, 1.759, 1.978, and 2.179 MeV were not observed to be populated by the (He^3,d) reaction. These levels may correspond to the

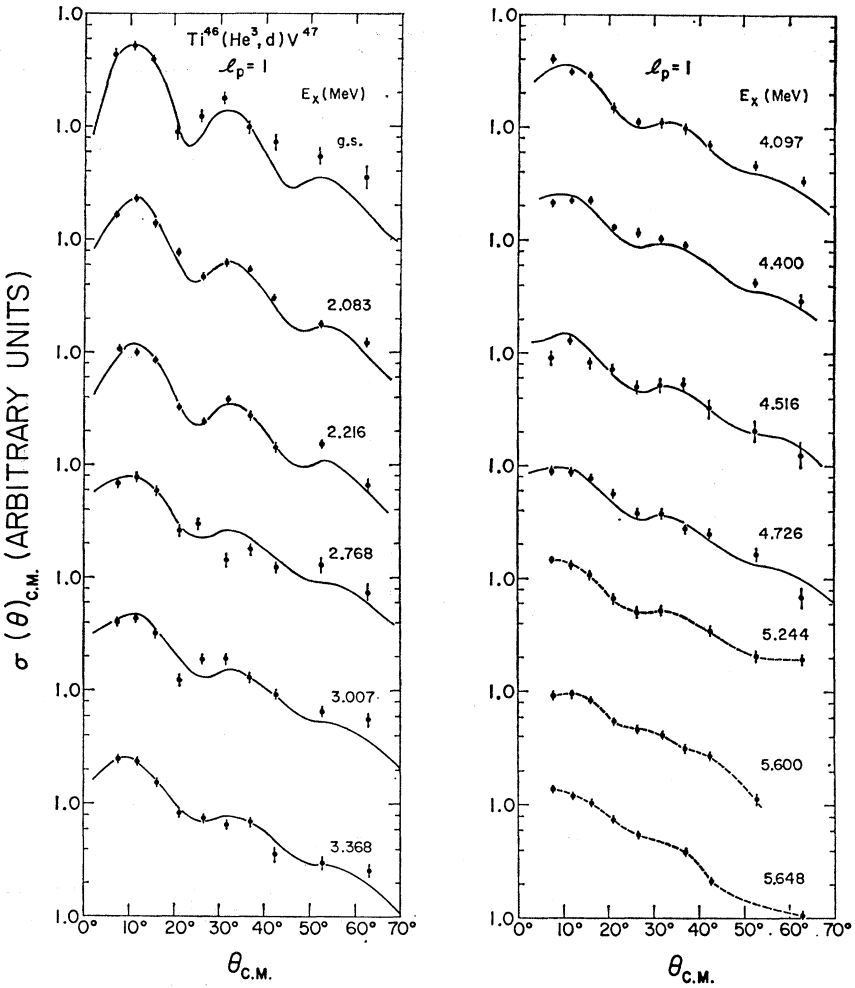

FIG. 2. Deuteron angular distributions corresponding to orbital angular momentum transfer $l_p=1$ observed in the $Ti^{46}(He^3,d)V^{47}$ reaction. The solid curves are the results of DWBA calculations.

high-spin states arising from the $(1f_{7/2})^3$ proton configuration or to states with more complex configurations which cannot be readily excited by the (He^3,d) reaction. The agreement with the remaining levels is seen to be very satisfactory.

The absolute cross sections given in column 5 are the values obtained at the first maximum of the angular distributions (second maximum for $l_p=0$ transitions) and have an estimated uncertainty of 30% due to target thickness. For nonstripping transitions they were measured at 25°. In view of the rather large uncertainty in cross sections, values of the spectroscopic factors were normalized by requiring a total of six proton holes in the $1f_{7/2}$ shell and assuming the 0.147-MeV state takes the full $T=\frac{1}{2}$ component of the $1f_{7/2}$ strength. The values of C^2S so obtained are listed in the final column. The criteria employed for assuming the spin-values listed in column 6 are discussed below.

B. Levels Below 2-MeV Excitation Energy

1. The Ground State

Of particular interest in the present study is the unambiguous $l_p=1$ transition observed to the ground state of V^{47}. This clearly rules out the earlier tentative $\frac{5}{2}^-$ assignment for the ground state and limits the spin-parity to either $\frac{1}{2}^-$ or $\frac{3}{2}^-$. However, the possibility of $\frac{1}{2}^-$ may be reasonably eliminated for the following reasons: (1) The low $\log ft$ value of 4.9 observed in the $V^{47}(\beta^+)Ti^{47}$ (ground state) decay[4] suggests an allowed transition. Since the ground state of Ti^{47} is known to be $\frac{5}{2}^-$ this limits the spin-parity of V^{47} to $\frac{3}{2}^-$, $\frac{5}{2}^-$, or $\frac{7}{2}^-$. (2) If it is assumed that the ground state of V^{47} is described mainly by the $(1f_{7/2})^3$ proton configuration, then a $J=\frac{1}{2}$ state is excluded by the Pauli principle. The weak $l_p=1$ transition observed in the present work nevertheless indicates a small admixture of the $(1f_{7/2})^2(2p_{3/2})$ configuration in the ground state.

It is interesting to note that the earlier $\frac{5}{2}^-$ assignment for V^{47} was not entirely consistent even with its known β^+ decay, since the 0.161-MeV $(\frac{7}{2}^-)$ state in Ti^{47} is not populated in the decay.[11] This is in accord, however, with a second forbidden transition from a $J^\pi=\frac{3}{2}^-$, V^{47} ground state.

[11] Baruch Rosner and Lars Broman, Nucl. Phys. **A100**, 59 (1967).

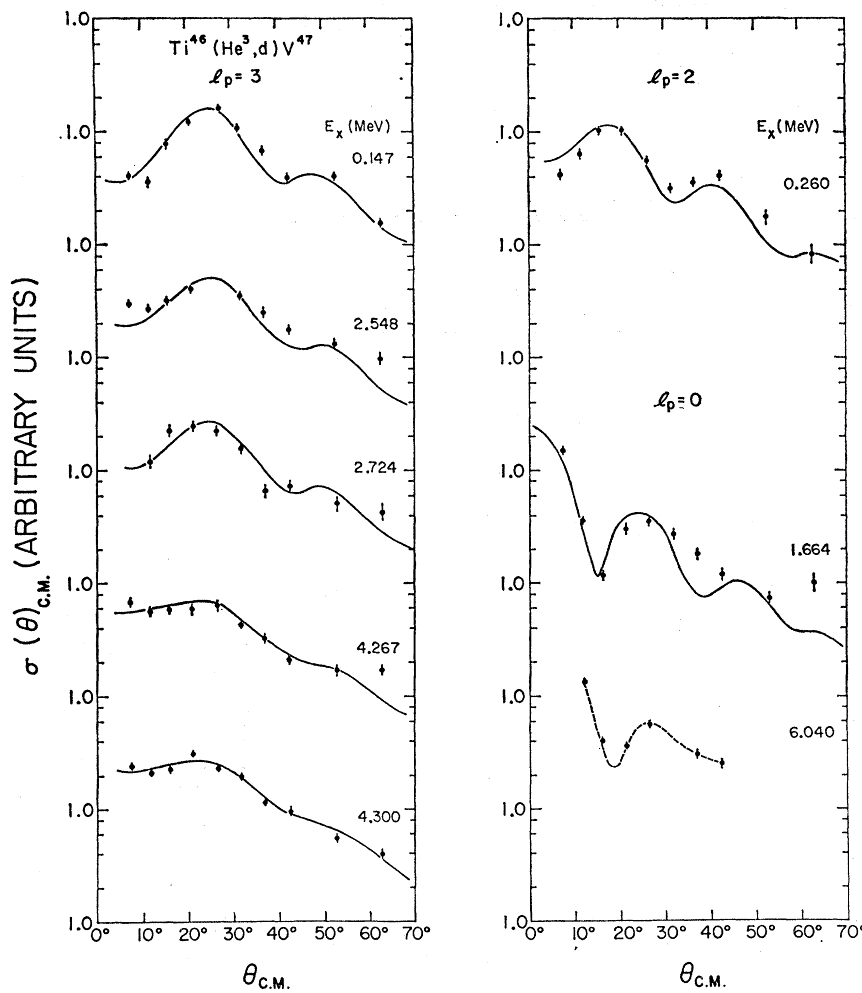

FIG. 3. Deuteron angular distributions corresponding to orbital angular momentum transfers $l_p=0$, 2, and 3 observed in the Ti^{46}-$(He^3,d)V^{47}$ reaction. The solid curves are the results of DWBA calculations.

2. *The 0.089-MeV and 0.147-MeV Levels*

The $l_p=3$ transition to the 0.147-MeV level restricts its spin and parity to either $\frac{5}{2}^-$ or $\frac{7}{2}^-$. However, in view of the low-excitation energy of this level and the strength of the transition, the level can most likely be identified as the $\frac{7}{2}^-$ state arising from the $(1f_{7/2})^3$ proton configuration. Since no other $l_p=3$ transitions are observed to low-lying states in V^{47} and none of the additional predicted $\frac{7}{2}^-$ states is expected to take any transition strength,[6] this level is also assumed to take the full $1f_{7/2}(T=\frac{1}{2})$ strength. Its spectroscopic factor has thus been normalized to the sum-rule limit of $C^2S[J=\frac{7}{2},\ T=\frac{1}{2}]=0.58$, as determined from the equations of French and MacFarlane.[12]

Talmi[13] has pointed out that low-lying states with $J=j-1$ are observed in many nuclei having a j^3 configuration. For example, in the $1f_{7/2}$ shell low-lying $\frac{5}{2}^-$ states are observed which generally lie rather close in energy to the $\frac{7}{2}^-$ levels arising from the $(1f_{7/2})^{\pm 3}$ configurations. Moreover, in most cases the measured $(J=\frac{5}{2})$-$(J=\frac{7}{2})$ energy separation agrees well with the predicted value. However, if in the present case the Ti^{46} target nucleus has the principal proton configuration $(1f_{7/2})_0{}^2$, then the $\frac{5}{2}^-$ state arising from the $(1f_{7/2})^3$ proton configuration in V^{47} cannot be excited by a first-order direct stripping reaction, since it involves a rearrangement of the three odd protons. Any admixture of the $(1f_{7/2})_0{}^2(1f_{5/2})$ proton configuration in this state, which could then be reached by a direct $l_p=3$ transition, should be very weak since the $\mathbf{l}\cdot\mathbf{s}$ interaction results in a splitting of the $1f_{7/2}$ and $1f_{5/2}$ single-particle states by at least 4 MeV.

The most likely candidate for the $\frac{5}{2}^-$ level in V^{47} arising from the $(1f_{7/2})^3$ configuration is the first excited state at 0.089 MeV, since it lies close to the $\frac{7}{2}^-$ state at 0.147 MeV and is only very weakly excited in the (He^3,d) reaction. This is also consistent with the systematic trend for the $\frac{5}{2}^-$ level in going from V^{51} [10] to V^{47}, as can be seen from Fig. 4. Unfortunately, because of the very weak transition to this state, and the

[12] J. B. French and M. H. MacFarlane, Nucl. Phys. **26**, 168 (1961).

[13] I. Talmi, Rev. Mod. Phys. **34**, 704 (1962).

TABLE I. Summary of experimental results for $Ti^{46}(He^3,d)V^{47}$. The excitation energies obtained in the present study are listed in column 2. The estimated uncertainty in excitation energy is ±12 keV for levels up to 2 MeV, ±15 keV for levels between 2 and 4 MeV, and ±20 keV for higher excited levels. The absolute cross sections listed in column 5 are the values at the first maximum in the angular distributions for $l_p=1$, 2, and 3 transitions and the second maximum for $l_p=0$ transitions. For nonstripping transitions they are the values obtained at 25°. All cross sections have an estimated uncertainty of ±30%.

Level	Present Study Ex (MeV)	Brown *et al.*[a] Ex (MeV)	l_p	$\sigma(\Theta)$ (mb/sr)	J^{Π} Assumed	C^2S
0	0	0	1	0.58	$\frac{3}{2}^-$	0.04
1	0.089	0.089		0.11	$(\frac{5}{2}^-)$	
2	0.147	0.149	3	1.42	$\frac{7}{2}^-$	0.58
3	0.260	0.267	2	0.45	$\frac{3}{2}^+$	0.08
4	0.661	0.671				
		1.148				
5	1.285	1.281		0.04		
		1.306				
6	1.664	1.672	0	0.28	$\frac{1}{2}^+$	0.06
		1.759				
		1.978				
7	2.083	2.092	1	7.03	$\frac{3}{2}^-$	0.35
		2.179				
8	2.216	2.221	1	2.94	$(\frac{3}{2}^-)$	0.15
9	2.430			0.04		
10	2.548		3	0.40	$\frac{5}{2}^-$	0.23
11	2.724		3	0.29	$\frac{5}{2}^-$	0.16
12	2.768		1	0.14	$(\frac{3}{2}^-)$	0.07
13	3.007		1	0.55	$(\frac{3}{2}^-)$	0.03
14	3.368		1	0.63	$(\frac{1}{2}^-)$	0.07
15	3.516			0.10		
16	3.595					
17	3.875					
18	3.986			0.04		
19	4.097		1	1.81	$(\frac{1}{2}^-)$	0.21
20	4.155			0.07		
21	4.195			0.07		
22	4.267		3	0.35	$\frac{5}{2}^-$	0.14
23	4.300[b]		3	1.09	$\frac{7}{2}^-$	0.20
24	4.400		1	1.03	$(\frac{1}{2}^-)$	0.12
25	4.516		1	0.20	$(\frac{1}{2}^-)$	0.02
26	4.613			0.17		
27	4.726		1	0.49	$(\frac{1}{2}^-)$	0.05
28	5.056					
29	5.157			0.13		
30	5.210			0.07		
31	5.244		1	1.52	$(\frac{1}{2}^-)$	0.17
32	5.387			0.16		
33	5.474			0.17		
34	5.538					
35	5.600		1	0.83	$(\frac{1}{2}^-)$	0.09
36	5.648[b]		1	2.82	$\frac{3}{2}^-$	0.14
37	5.711			0.56		
38	5.748			0.35		
39	5.859			0.42		
40	5.882			0.86		
41	5.928			0.27		
42	6.040		0	0.40	$\frac{1}{2}^{+c}$	
43	6.176			0.42		
44	6.284					
45	6.399			0.30		
46	6.431			0.34		
47	6.570			0.14		
48	6.708			0.50		
49	6.749			0.21		
50	6.895			0.13		
51	6.948			0.57		
52	7.008			0.66		

[a] See Ref. 1.
[b] Analog state.
[c] State too unbound to extract reliable spectroscopic factor.

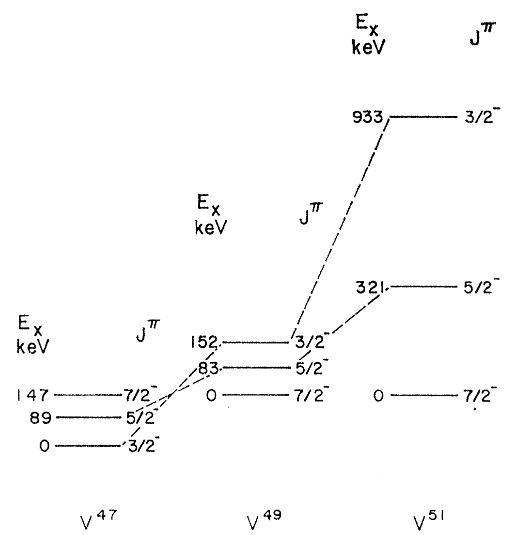

FIG. 4. Excitation energies of the lowest-lying $\frac{7}{2}^-$, $\frac{5}{2}^-$, and $\frac{3}{2}^-$ states in V^{47}, V^{49}, and V^{51}.

relatively strong $l_p=1$ transition to the 1.663-MeV level in V^{49} which occurs in its immediate neighborhood, its angular distribution could not be readily extracted. It was therefore not possible to determine if the level is excited by a second-order stripping mechanism, as is believed to have been observed for similar $\frac{5}{2}^-$ levels in other nuclei.[10,14]

3. *The 0.260-MeV and 1.664-MeV Levels*

The level at 0.260 MeV is excited with orbital angular momentum transfer $l_p=2$, and must therefore have a spin-parity of either $\frac{3}{2}^+$ or $\frac{5}{2}^+$. However, since no $2d_{5/2}$ states are expected at such a low excitation energy, the level most probably arises from a $1d_{3/2}$ proton-hole configuration. Bansel and French[15] have derived a simple formula to predict the excitation energies of the $1d_{3/2}$ and $2s_{1/2}$ hole states in the Sc and Ti isotopes. A straightforward extension of this formula to V^{47} using their suggested empirical parameters places the $\frac{3}{2}^+$ hole state at 0.39-MeV excitation energy, in reasonable agreement with the observed location.

The level at 1.664 MeV can only have a spin-parity of $\frac{1}{2}^+$ since it is excited by a $l_p=0$ transition. It can most probably be identified, then, as a $2s_{1/2}$ proton hole state. The predicted position of this state obtained from the formula of Bansel and French is about 1.0 MeV, in this case in rather poor agreement with the observed value. It may be, however, that the empirical parameters which are required to describe the hole states in the Ti and Sc isotopes are not suitable for V^{47}.

From the measured spectroscopic factors for these two even-parity states, the $1d_{3/2}$ and $2s_{1/2}$ proton shells

[14] T. A. Belote, W. E. Dorenbusch, O. Hansen, and J. Rapaport, Nucl. Phys. **73**, 321 (1965).
[15] R. K. Bansel and J. B. French, Phys. Letters **11**, 145 (1964).

in Ti^{46} are estimated to be about 92% and 94% filled, respectively. In cases such as these, however, in which the spectroscopic factors are very small, experimental uncertainties and the shortcomings of the distorted-wave theory tend to place large uncertainties on such estimates. It is interesting to note that a spectroscopic factor of 0.6 was obtained by Schwartz and Alford[16] for the transition leading to the $\frac{3}{2}^+$ proton hole state in Sc^{45}. If this is so, this would require more than two $1d_{3/2}$ proton holes in the ground state of Ca^{44} which are almost filled in Ti^{46}.

4. The 0.671-MeV and 1.281-MeV Levels

The levels at 0.671 and 1.281 MeV were only very weakly excited by this reaction. These levels may therefore correspond to the high-spin states arising from the $(1f_{7/2})^3$ proton configuration which cannot be reached by a direct stripping mechanism, or to states with more complex configurations.

C. Levels Above 2-MeV Excitation Energy

1. $l_p=3$ Transitions

Two intense $l_p=3$ transitions are observed to states at 2.548 and 2.724 MeV. Since the 0.147-MeV level takes most, if not all, of the $T=\frac{1}{2}$, $1f_{7/2}$ strength, these two states most probably have a spin parity of $\frac{5}{2}^-$. The only other $l_p=3$ transitions observed occur to states at 4.267 and 4.300 MeV. At this excitation energy the $T=\frac{3}{2}$ analog state to the $\frac{7}{2}^-$ level at 0.161 MeV in Ti^{47} [17] is expected. In view of the small separation of these states, however, and also the possibility of fragmentation of the analog state,[18] the choice of one as the analog cannot readily be made on the basis of excitation energy alone. However, the large difference in cross sections for these two transitions, and a comparison with the available sum rules for the total transition strengths, strongly suggests that the 4.300-MeV level is the analog state. Thus, the measured spectroscopic factor of $C^2S[J=\frac{7}{2}]=0.20$ for this level is in quite close agreement with the predicted value of 0.17 for the analog state. Furthermore, it is unreasonable to assume that both levels are fragments of the analog state, since this would yield a total transition intensity to the analog which exceeds the sum rule limit by more than 70%. The 4.267-MeV level is therefore most probably $\frac{5}{2}^-$. On the basis of these spin assignments, the transitions to the three levels at 2.548, 2.724, and 4.267 MeV take nearly 80% of the total $1f_{5/2}$ transition strength. From the measured excitation energy of 4.300 MeV for the analog state to the 0.161-MeV level in Ti^{47}, the Coulomb displacement energy for the V^{47}-Ti^{47} pair is calculated to be $\Delta E_c=7.84\pm0.02$ MeV.

[16] J. J. Schwartz, W. Parker Alford, and A. Marinov, Phys. Rev. **153**, 1248 (1967).

[17] J. Rapaport, A. Sperduto, and W. W. Buechner, Phys. Rev. **143**, 808 (1966).

[18] C. Bloch and J. P. Schiffer, Phys. Letters **12**, 22 (1964).

2. $l_p=1$ Transitions

Two intense $l_p=1$ transitions were observed to states at 2.083- and 2.216-MeV excitation energy, and a further two to states at 4.097 and 4.400 MeV. Since the spin-orbit interaction is expected to result in a splitting of the $2p_{3/2}$ and $2p_{1/2}$ single-particle states by about 2 MeV, it seems reasonable to assign a spin-parity of $\frac{3}{2}^-$ to the lower pair of states and $\frac{1}{2}^-$ to the upper pair. In addition, a $\frac{1}{2}^-$ assignment for the 2.083-MeV level is very unlikely since this would give it a spectroscopic factor which alone exceeds the total $2p_{1/2}$ transition strength by 15%. The $\frac{3}{2}^-$ assignment for this state is also in accord with its gamma branching ratio, as observed in the $Ti^{46}(p,\gamma)$ study of Albinson and Dubois.[2]

In the case of the $Ti^{46}(d,p)Ti^{47}$ reaction, a strong $l_n=1$ transition is known[17] to occur to the level at 1.545 MeV in Ti^{47}, which is presumably a $\frac{3}{2}^-$ state arising mainly from the $2p_{3/2}$ neutron configuration. Its analog in V^{47} is thus expected at about 5.68-MeV excitation energy. In addition to the four transitions already mentioned, only one other intense $l_p=1$ transition is in fact observed in the present study, and this occurs to the level at 5.648 MeV. This level can probably be identified, then, as the $\frac{3}{2}^-$ analog to the 1.545-MeV state in Ti^{47}. Furthermore, the measured spectroscopic factor of $C^2S[J=\frac{3}{2}]=0.14$ for this level is in excellent agreement with the predicted value of 0.15 for the $\frac{3}{2}^-$ analog state.[12,17] The energy separation between the $\frac{7}{2}^-$ and $\frac{3}{2}^-$ analog states in V^{47} is found to be 1.348 ± 0.015 MeV, whereas the energy separation between the corresponding levels in Ti^{47} is 1.388 ± 0.012 MeV. However, discrepancies of this magnitude are found to be typical of many $T=\frac{3}{2}$ analog pairs throughout the $1f_{7/2}$ shell.[19]

The remaining $l_p=1$ transitions are all relatively weak and do not permit any clear distinction to be made between $\frac{1}{2}^-$ and $\frac{3}{2}^-$ states. However, if all the observed $l_p=1$ transitions are considered together, then the value of $\Sigma(2J+1)C^2S$, which is obtained by summing over all $T=\frac{1}{2}$ components of the $2p_{3/2}$ and $2p_{1/2}$ states, is found to be 4.0 Although the agreement with the predicted value of 4 is probably fortuitous, it indicates at least that most of the $2p_{3/2}$ and $2p_{1/2}$ strengths are, in fact, observed in the present study.

Since the $2p_{3/2}$ and $2p_{1/2}$ states can not be distinguished on the basis of the observed $l_p=1$ transitions alone, then their centroids cannot be readily determined. Nevertheless, a rather crude estimate may be made if it is assumed that the low-lying levels formed by $l_p=1$ transitions correspond to $p_{3/2}$ states. The number of these levels to be taken into account can be determined by summing the values of C^2S until the theoretical limit of 0.67 is reached; the remaining levels are then assumed to be $p_{1/2}$ states. The level spins thus assumed are given in column 6 of Table I, and these lead to centroids located at 2.2 MeV for the $2p_{3/2}$

[19] B. Rosner and D. J. Pullen, Phys. Letters **24B**, 454 (1967).

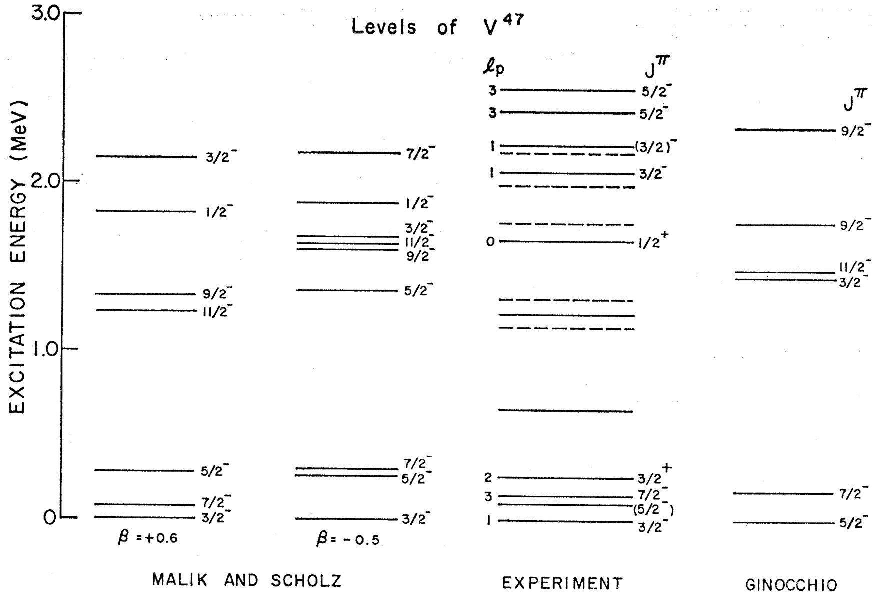

FIG. 5. A comparison between the observed low-lying levels of V^{47} and the predicted level schemes of Ginocchio (Ref. 6) and Malik and Scholz (Ref. 7). In the latter case the best agreement is shown for both a prolate and an oblate deformation. The levels indicated by broken lines were observed in the study by Brown *et al.* (Ref. 1) but not in the present study.

states and 4.6 MeV for the $2p_{1/2}$ states. However, these values are clearly subject to considerable uncertainties.

IV. CONCLUSIONS

Ginocchio[6] has calculated the low-lying states in V^{47} assuming a pure $(1f_{7/2})^n$ configuration and an effective two-nucleon residual interaction. Although the predicted separation of the first $\frac{7}{2}-$ and $\frac{5}{2}-$ states agrees well with experiment, the location of the $\frac{3}{2}-$ state arising from this configuration is not at all well reproduced. Thus, whereas this state is predicted to lie at 1.44-MeV excitation, it is in fact the ground state. Depressions of the $\frac{3}{2}-$ state by 1 MeV or more had also previously been noted by McCullen, Bayman, and Zamick[5] for other odd-A nuclei in the $1f_{7/2}$ shell.

This large discrepancy is probably due to the interaction with $\frac{3}{2}-$ states arising from other configurations, e.g., $(1f_{7/2})_0{}^2(2p_{3/2})$ and $(1f_{7/2})_2{}^2(2p_{3/2})$, the former states being observed at about 2 MeV in V^{47}. It is known from the calculations of Auerbach[20] that the inclusion of such configurations in the case of V^{51} succeeds in lowering the first predicted $\frac{3}{2}-$ state to its observed location, and also to yield the correct transition intensity in the $Ti^{50}(He^3,d)$ reaction leading to it.[21] Unfortunately, such calculations involving configuration mixing cannot easily be extended to V^{47} in view of the additional problems introduced by the four extra neutrons.

An alternative approach to the study of V^{47} is that of Malik and Scholz,[7] who have used the strong-coupling symmetric rotator model, with Coriolis coupling between bands. According to their calculations the observed $\frac{3}{2}-$ ground state and low-lying levels in V^{47} can be rather well reproduced, providing that either a large oblate or a large prolate deformation is assumed. The calculated level schemes which are in best agreement with experiment correspond to deformation parameters of $\beta=+0.6$ and $\beta=-0.5$. These level schemes, together with that of Ginocchio, are compared with the empirical level scheme in Fig. 5.

An interesting test of the applicability of the Coriolis coupling model to nuclei in the $f_{7/2}$ shell could be obtained by measuring the quadrupole moments of the $\frac{3}{2}-$ ground state and $\frac{7}{2}-$ (0.147 MeV) state in V^{47}. According to Malik and Scholz,[22] these moments should have opposite signs. Thus, for $\beta=-0.5$, $Q(J=\frac{3}{2})=-0.204$ b and $Q(J=\frac{7}{2})=+0.222$ b, and for $\beta=+0.6$, $Q(J=\frac{3}{2})=+0.277$ b and $Q(J=\frac{7}{2})=-0.468$ b. Such a test, of course, suffers from the problem of measuring the quadrupole moment of an excited state. However, both V^{47} and V^{49} fall within the same group classification of Malik and Scholz,[7] have the same rotational constant, as derived from the first 2^+ state in neighboring even-even nuclei, and should have similar deformations. The quadrupole moment of the excited $\frac{7}{2}-$ state in V^{47} could thus be estimated from a measurement of the moment of the V^{49} ground state.

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