were used in the calculation of multipole coefficients by Moinester *et al.*[21] As mentioned before, their results show a significant difference between the monopole coefficients for Sc^{42} and Sc^{48}. Although the above assignments have to be checked by further experiments, it seems evident that there are considerable admixtures in either Sc^{42} or Sc^{48} or in both, since the calculated monopole coefficients are rather insensitive to the positions of individual levels.

The large discrepancy in the expected 2^+ energy is not as serious as it seems. We have made a least-squares fit to the known states in Sc^{42} and Sc^{48} making use of the Pandya transformation

$$E_{\rm ph}{}^{J}=C-\sum_{J'}(2J'+1)W(\tfrac{7}{2}\tfrac{7}{2}\tfrac{7}{2}\tfrac{7}{2};J'J)E_{\rm pp}{}^{J'}.$$

A total of nine parameters (8 value of $E_{\rm pp}{}^{J'}$ and C) were fitted to the 16 experimental energies. The resultant fitted energies are compared with the observed ones in Table II and, while it is clear that the 2^+ state in Sc^{48} deviates more than other states, the difference in this deviation is not excessive. The rms deviation is 125 keV. The ~500-keV discrepancy in the average two-body energies derived from Sc^{48} and Sc^{42} was discussed by Moinester *et al.*[21] and admixtures in Sc^{42} were suspected. It would seem quite possible that such admixtures would cause more than just a centroid shift and some of the other discrepancies may well have their source in such admixture. Shell-model calculations[28,29] predict large admixtures in the 1^+, 3^+, and 5^+ states of Sc^{42} and this may be the source of some of the deviations. Results, as yet somewhat contradictory, are becoming available on the $(f_{7/2})^2$ spectrum[12,25,30] in Co^{54}, and when this spectrum is understood one can perform some further interesting comparisons.[31]

[28] T. T. S. Kuo and G. E. Brown, Nucl. Phys. **A114**, 241 (1968).
[29] F. Pühlhofer, Nucl. Phys. **A116**, 516 (1968).
[30] J. J. Schwartz, R. Sherr, and T. Bhatia, Bull. Am. Phys. Soc. **13**, 1446 (1968).
[31] D. S. Koltun and B. J. West, in *Contributions to the International Conference on Properties of Nuclear States* (Les Presses de l' Université de Montréal, Montreal, 1969), p. 218.

PHYSICAL REVIEW C VOLUME 1, NUMBER 2 FEBRUARY 1970

Investigation of ^{46}Sc by the Reaction ^{47}Ti(d, ^{3}He)^{46}Sc

M. B. Lewis*
Nuclear Physics Laboratory, University of Pittsburgh, Pittsburgh, Pennsylvania 15213

(Received 1 October 1969)

Angular distributions from the ^{47}Ti(d, ^{3}He)^{46}Sc and ^{48}Ti(d, ^{3}He)^{46}Sc reactions have been measured with a deuteron beam energy of 17 MeV. The ^{3}He particles were magnetically analyzed by position-sensitive counters and photographic emulsions mounted in an Enge split-pole spectrograph with typical experimental resolutions of 8-10 keV full width at half-maximum. With the use of distorted-wave Born-approximation calculations for $2s_{1/2}$, $1d_{3/2}$, $1f_{7/2}$, and $2p$ pickup, l_p values and spectroscopic factors were deduced. The results verify a finite (≈0.2 protons) occupation in the $2p$ orbitals. In addition, the $1f_{7/2}$ orbit appears in slight excess and $1d_{3/2}$ is slightly deficient in its shell-model value of protons. By comparison with other studies in ^{46}Sc, it is concluded that the similar average binding energies for $\pi f_{7/2}\nu(f_{7/2}{}^5)_{7/2}$, $\pi f_{7/2}\nu(f_{7/2}{}^5)_{5/2}$, and $\pi(d_{3/2}{}^{-1})(f_{7/2}{}^2)_0\nu(f_{7/2}{}^5)_{5/2}$ configurations are primarily responsible for the high level density and large configuration mixing in the 0–1-MeV excitation in ^{46}Sc. In the 1–2-MeV region, the $\pi(s_{1/2}{}^{-1})(f_{7/2}{}^2)_0\nu(f_{7/2}{}^5)_{5/2}$, $\pi d_{3/2}{}^{-1}(f_{7/2}{}^2)_0\nu(f_{7/2}{}^5)_{7/2}$, $\pi d_{3/2}{}^{-1}(f_{7/2}{}^2)_0\nu d_{3/2}{}^{-1}(f_{7/2}{}^6)_0$, and $\pi f_{7/2}\nu(f_{7/2}{}^4)_0 2p^1$ configurations dominate the spectrum.

I. INTRODUCTION

In previous investigations of ^{46}Sc, it has been evident that the level density of low-lying states and the shell-model configuration mixing is quite large in this odd-odd $f_{7/2}$-shell nucleus.[1–4] Due to the presence of both positive- and negative-parity states in the first MeV of excitation in ^{46}Sc, it is especially important that the levels be studied in as many different ways as possible. Thus, the proton pickup reaction study in this work supplements previous (d, p),[1] (d, α),[4] and (n, γ)[2,3] work. Furthermore, the high level density demands high-resolution techniques which were not available in the earlier (d, ^{3}He) work of Yntema and Satchler.[5] In fact, no individual levels in ^{46}Sc were resolved in this earlier attempt.

Nevertheless, several isotopes of scandium were investigated in (d, ^{3}He) studies of Ref. 5 and it was

* Present address: Nuclear Data Project, Oak Ridge National Laboratory, Oak Ridge, Tenn. 37830.
[1] J. Rapaport, A. Sperduto, and W. W. Buechner, Phys. Rev. **151**, 939 (1966).
[2] H. H. Bolotin, Phys. Rev. **168**, 1317 (1968).
[3] D. B. Fossan, C. Chasman, and K. W. Jones, Phys. Rev. **168**, 1200 (1968).
[4] M. B. Lewis, Phys. Rev. **184**, 1081 (1969).
[5] J. L. Yntema and G. R. Satchler, Phys. Rev. **134**, B976 (1964). The resolution in this work was ≈300-keV FWHM.

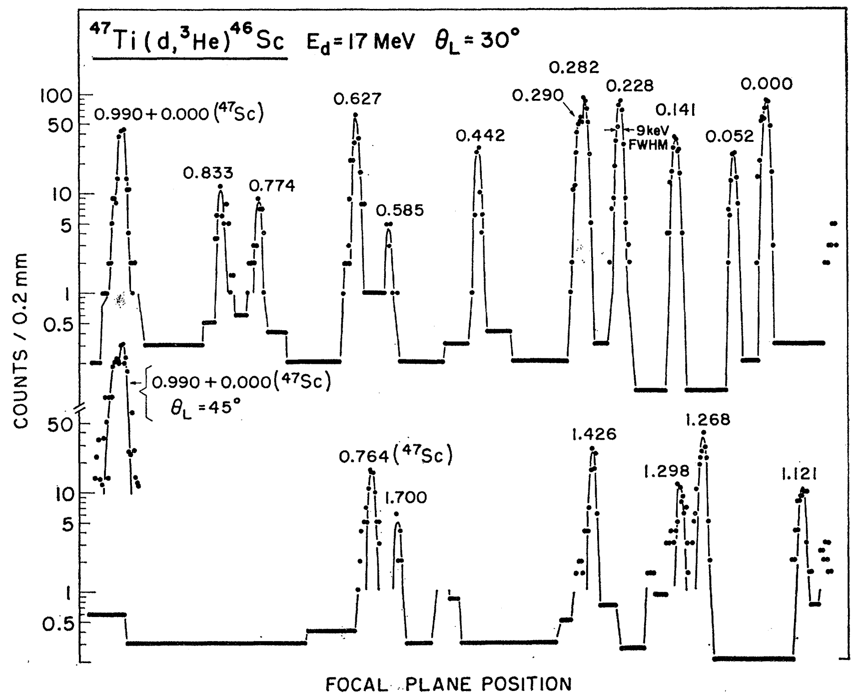

FIG. 1. Typical spectrum from the reaction ^{47}Ti(d, ^{3}He)^{46}Sc with 17-MeV incident beam in which reaction products were detected at $\theta_L=30°$. Also shown are two states from the reaction ^{48}Ti(d, ^{3}He)^{47}Sc due to a 17% ^{48}Ti contaminant isotope and a spectrum of the 0.99-MeV region at $\theta_L=45°$. In regions of less than 1 count/0.2 mm, average background lines have been drawn. Excitation energies have been indicated for ^{46}Sc and ^{47}Sc, and energy errors are given in Table I.

evident from the relative strengths of $f_{7/2}$, $d_{3/2}$, and $s_{1/2}$ proton pickup that the proton binding energies were very sensitive to the neutron occupation number in the $f_{7/2}$ shell.

In this work an attempt is made to view the ^{46}Sc levels below $\approx$2 MeV in more detail by carrying out the (d, ^{3}He) study with much higher resolution and comparing the proton pickup results with the (d, p), (d, α), and (n, γ) investigations.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

Titanium films of about 20–30 μg/cm^2 were prepared by electron-gun evaporation of Ti_2O_5 powder (80.5% ^{47}Ti, 16.5% ^{48}Ti, 3% ^{46,49,50}Ti). The TiO vapor condensed on a 10-μg/cm^2 carbon film and was mounted on a target frame with a 0.5-in.-high and 0.25-in.-wide aperture. The 17% ^{48}Ti was sufficient to investigate the first two levels of ^{47}Sc, but states from the

$$^{46,49,50}\text{Ti}(d,\,^3\text{He})^{45,48,49}\text{Sc}$$

were not identified.

The ^{47,48}Ti(d, ^{3}He)^{46,47}Sc reactions were investigated with a deuteron beam energy of 17 MeV. The beam currents from the University of Pittsburgh three-stage tandem Van de Graaff were typically $\sim$0.5 μA on the Ti target. Details of the beam geometry have been given previously.[4] The ^{3}He particles were detected by an array of four position-sensitive counters mounted in an Enge split-pole magnetic spectrograph. A further description of this method has been reported.[6] Reaction spectra were taken at 15°, 25°, and 45° with the position counters in which a total charge of 6000–8000 μC was accumulated. In addition, spectra at 35°, 40°, and 60° were taken with K-1 Ilford photographic plates.

At any given point in the focal plane, the energy of the projectile of charge Z and mass M is proportional to Z^2/M. Aside from projectiles of $Z\geq 3$, of which none were observed, the ^{3}He was the most energetic. While using position counters a discriminator was, therefore, set between ^{3}He and ^{4}He pulse heights which originated from the E (total energy) terminal of each position counter, and the discriminator output was used to gate the XE (position-energy product) signal for the pulse-height spectrum. Four position counters were utilized and this corresponds to $\approx$2.6 and 1.7 MeV of excitation region for ^{46}Sc and ^{47}Sc, respectively.

The purpose of using the photographic emulsions was to obtain a more accurate energy calibration than would be possible with noticeably nonlinear position counters. It was also of interest to note what particle-identification problems occurred with α-sensitive Ilford K-1 photographic emulsions. The 35° spectrum was taken with a thin ($\approx\frac{1}{4}$ mil) aluminum absorber over the plates and is shown in Fig. 1. With this absorber there was little projectile energy loss and the ^{3}He completely penetrated the 50-μ emulsion. Individual ^{3}He tracks could be easily distinguished from the ^{4}He tracks which stopped in the emulsion and were noticeably shorter. On the other hand, the frequency of ^{4}He

[6] W. W. Daehnick, Phys. Rev. 177, 11 (1969).

TABLE I. A list of energy levels and spectroscopic properties found in the present (d, ^{3}He) study. First column: Q values, energy levels, and energy errors for ^{47}Ti and ^{48}Ti targets. Second column: proton angular momentum transfers as explained in text. Third and fourth columns: spectroscopic factors with errors expected at 20%. The third column is normalized without any finite range or nonlocality correction. The fourth column is normalized to the value of $S=4.0$ for the 0.764-MeV level of ^{47}Sc and is preferred by the author. See text for details. The fifth column contains the spectroscopic factors for the $l_n=3(d, p)$ measurements of Ref. 1 assuming spin-parity values in column 6. The sixth column represents the author's best estimate as to the spin parity of low-lying ^{46}Sc levels taking into consideration the work in Refs. 1–4 and this work. Above 1 MeV only levels seen in this work are listed.

Excitation (MeV) $Q=-4.970\pm0.010$ (^{46}Sc)	l_p	S_l^z $\Delta S/S\approx0.2$	$S^i(d, {}^{3}\text{He})$	$S(d, p)$ ($l_n=3$)	J^π
0.000	3	0.65	0.53	0.52	4^+
	(1)	(0.08)	(0.07)		
0.052±3	3	0.22	0.18	0.82	6^+
0.141±3	2	0.48	0.39		1^-
0.228±3	3	0.55	0.45	0.71	3^+
	(1)	(0.07)	(0.06)		
0.282±3	(3)	(0.64)	(0.52)	~0.00	5^+
0.290±3	(2)	(0.46)	(0.38)		2^-
0.442±3	(3)	(0.14)	(0.11)	0.50	2^+
	(1)	(0.03)	(0.02)		
0.585±3	0	0.63	0.52		3^-
0.627±4	2	0.91	0.75		4^-
0.774±4	3	0.11	0.09	0.61	5^+
0.833±4	3	0.23	0.19	0.23	4^+, (5^+)
0.975–assumed		(0.00)	(0.00)	0.27	7^+
0.990±4	3	0.21	0.17	~0.00	1^+
1.121±5	3	0.13	0.11	~0.00	2^+–4^+
1.268±5	0	0.65	0.53		2^-, 3^-
	2	0.95	0.73		
(1.298)±5	(2)	(0.13)	(0.11)		
1.426±5	0	0.44	0.36		2^-, 3^-
	2	0.59	0.46		
1.700±6	0	0.20	0.16		2^-, 3^-
$Q=5.953\pm0.010$ (^{47}Sc)					
0.000	3	2.4	2.0		$\frac{7}{2}^-$
0.764±4	2	4.9	4.0		$\frac{3}{2}^+$

tracks made scanning difficult, so a thick (≈1.0 mil) absorber was used for 40° and 60° runs. In this case, the ^{4}He projectiles were stopped in the absorber. However, lower-energy deuteron tracks, faint but quite copious and approximately the same length as the ^{3}He, clouded the spectrum, and only part of this data was useful. Presumably, slight modifications in the nuclear-emulsion developing technique would correct for this problem although none were attempted in this work.

III. EXPERIMENTAL RESULTS

On the spectrum shown in Fig. 1, the excitation energies[7] in ^{46,47}Sc are indicated. The measured Q values for the ^{48,47}Ti(d, ^{3}He) ^{47,46}Sc reactions are shown in Table I along with a tabulation of the levels. The resulting experimental resolution of 8–10-keV full width at half-maximum (FWHM) was sufficient to well resolve most of the ^{46}Sc peaks. The 0.282, 0.290-MeV doublet was partially separated at some angles, so that variations in the relative cross sections for the two groups could be qualitatively observed, and indicated that the 0.290 member was still increasing at 15°. This was the basis for assigning it a negative-parity state (see Sec. IV). An additional problem arose in the 0.990-MeV region of excitation in ^{46}Sc since this kinematically overlaps with the ground-state transition in ^{47}Sc. As pointed out in Ref. 4, the evidence from (n, γ), (d, p), and (d, α) studies are consistent with the existence of a 0.975, 0.991 doublet in ^{46}Sc. However, the lower member is

[7] The author is grateful to J. B. Moorhead and R. Moyer for the use of their energy-calibration computer code.

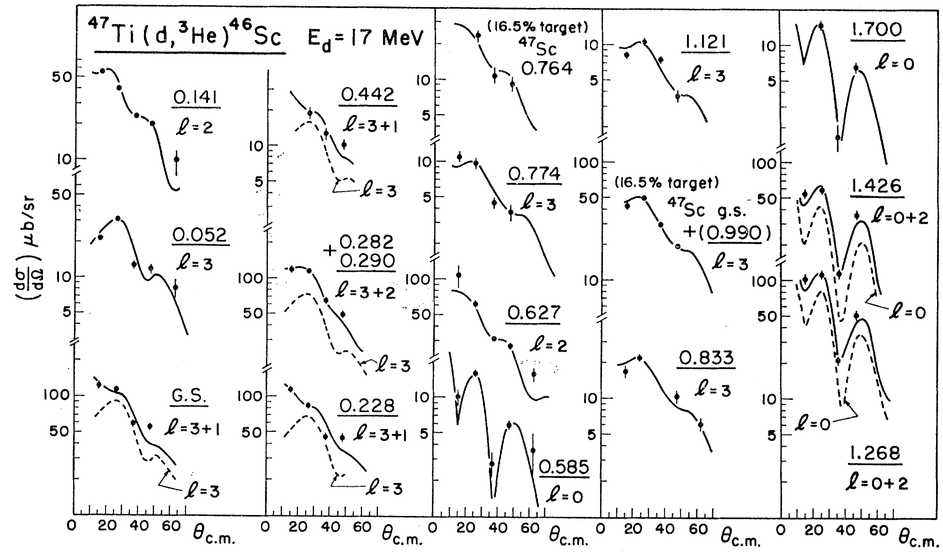

FIG. 2. Angular distributions from the reaction ^{47,48}Ti$(d, {}^3\text{He})^{46,47}$Sc at $E_d=17$ MeV. Errors are discussed in the text. The smooth curves are DWBA predictions. In case the measured distribution calls for l_p mixtures, the dominant l_p is given as a broken curve and the proper mixture as a continuous curve. All data are for ^{46}Sc unless otherwise mentioned.

believed to be a $J^\pi=7^+$ configuration and thus could not be directly excited in this $(d, {}^3\text{He})$ work due to the $J^\pi=\frac{5}{2}^-$ ground state of ^{47}Ti. The 45° data for this region is also shown in Fig. 1 to illustrate a relative kinematic shift apparently between two peaks. The lower-energy (i.e., higher excitation) member would be the 991-keV level reported in Ref. 2, while the remaining strength of the doublet is due to the ground-state transition of ^{47}Sc.

The differential cross sections for the Sc groups were determined by comparing the yield for the $(d, {}^3\text{He})$ reaction at 17 MeV with the elastic ($\theta_L=40°$) Ti(d, d) reaction yield at 11.8 MeV, the cross sections for the latter having been tabulated.[8] The experimental arrangements for the two reactions were essentially identical, and the elastic ^{16}O(d, d) was easily separated from Ti(d, d) with the position counters. The results of the angular distribution measurements are shown in Fig. 2. The absolute cross-section error should be taken as 15%, while the relative (mostly statistical) error is shown in the figure for each point. The smooth curves in Fig. 2 represent calculated values discussed below.

IV. ANALYSIS

The reaction analysis was carried out by use of distorted-wave Born approximations (DWBA). DWBA codes JULIE [9] and DWUCK [10] were made available and the optical-model parameters[11,12] used are shown in Table II. The form-factor well geometry was taken as $r_0=1.25$ F, $a=0.65$ F, and a Thomas spin-orbit strength $\lambda=25$ was included. Angular distributions resulting from $2p$, $1f_{7/2}$, $1d_{3/2}$, and $2s_{1/2}$ proton pickup were calculated with and without finite-range and nonlocality corrections. Changes in the shape of the computed curves were quite small after these corrections were included. However, the absolute cross-section prediction increased about 33% when the finite-range and nonlocality corrections were applied.

The smooth curves in Fig. 2 show the results of the computations. As pointed out in Ref. 4, one expects a measureable occupation of the $2p$ shell from valence nucleons. Further evidence in this work can be seen by comparing angular distributions from the ground (4^+) and 0.228 (3^+), in which $2p$ admixtures are allowed from angular momentum conservation, with the 0.052 (6^+) and 0.833 (5^+), in which $2p$ admixtures are not allowed due to the spin-parity $(\frac{5}{2}^-)$ of the target ground state. When $2p$ mixtures are allowed, the yields are greatest at 15°, rather than at 25° as expected from the DWBA owing to the 15° peak cross section of $2p$ angular distributions. One should be aware, however, that these $l=3+1$ mixtures are nearly identical in shape to the $l=2$ curves, and the validity of earlier parity determinations[1–4] have been assumed.

[8] G. Mairle and U. Schmidt-Rhor, Heidelberg Report No. 1965 IV 113, Max-Planck-Institut für Kernphysik, 1965 (unpublished).
[9] R. H. Bassel, R. M. Drisko, and G. R. Satchler, Oak Ridge National Laboratory Report No. 3240, 1963 (unpublished).
[10] P. D. Kunz (private communications).
[11] C. M. Perey and F. G. Perey, Phys. Rev. **132**, 755 (1963); note use of average parameters for deuteron channel in contrast to direct-search parameters used in Ref. 4.
[12] E. F. Gibson, B. W. Ridley, J. J. Kraushaar, M. E. Rickey, and R. H. Bassel, Phys. Rev. **155**, 1194 (1967).

TABLE II. A list of pertinent DWBA parameters in usual notation used to generate the curves in Fig. 2 and spectroscopic strengths in Tables I and III. A reference to the optical parameters is given in the text.

Channel	$\|V_0\|$ (MeV)	r_0 (F)	a (F)	r_c (F)	W (MeV)	W' (MeV)	r_I (F)	a_I (F)
d	90.0	1.15	0.81	1.15	0.00	19.2	1.34	0.68
^{3}He	177.0	1.14	0.72	1.40	15.7	0.00	1.62	0.86

Finite range (when included), $R=0.77$
Nonlocality (when included), $\beta_d=0.54$, $\beta_{\rm He}=0.25$
Form factor: $r_0=1.25$ F, $a=0.65$ F, $\beta_p=0$,
Binding energy $=10.46$ (MeV) $+E_x$ (MeV)

On the other hand, the $l=0$ transitions have a characteristic minima at $\approx 35°$ which is qualitatively reproduced by DWBA. Therefore, the cross section at 35° places an upper limit on $l=2$ admixtures to predominately $l=0$ angular distributions.

Spectroscopic factors were computed by comparing the DWBA predictions with the measured cross-section values

$$(d\sigma/d\Omega)_{\rm exp}=NS_l(d\sigma/d\Omega)_{\rm DWBA},$$

in which the normalization ($N=2.95$) was taken from approximation b of Bassel.[13] It is instructive to consider first the spectroscopic factors for the reaction ^{48}Ti(d, ^{3}He)^{47}Sc since in this even-even target case most of the transition strength for a given orbit is concentrated to a single level of the odd-A final state. The two levels of ^{47}Sc excited in this work are the ground state and the 0.764-MeV state which were previously identified as the $\pi f_{7/2}^{-1}$ and $\pi d_{3/2}^{-1}$ states, respectively.[14] The spectroscopic factors (S_l) obtained here are shown in Tables I and III. The superscript z represents values determined without finite-range and nonlocal corrections, b with finite range and nonlocal corrections using parameters listed in Table II, and i with undetermined, though intermediate, range and nonlocality parameters such as to give the full $d_{3/2}$ shell value of $S_2=4.0$ for ^{48}Ti. There is evidence from the dipole moment measurement by Fossan and Poletti[15] for the $d_{3/2}^{-1}$ (0.764) state that it contains no appreciable (i.e., $\gtrsim 10\%$) core-excitation component. Thus the spectroscopic values S^i in Tables I and III are believed to be the most nearly correct. This in turn implies that the (d, ^{3}He) range parameter (R) is slightly smaller than 0.77[15] and is thus intermediate between approximations a and b calculated by Bassel.[13]

The spectroscopic factors for the reaction ^{47}Ti(d, ^{3}He)^{46}Sc are given in Table I for S^z and S^i described above. The sums $\sum_k S_{jk}$ of spectroscopic factors for states (k) and the relative center of gravity $\langle E_x\rangle_j=\sum_k S_{jk}E_k-\langle E_x\rangle_{f_{7/2}}$ are given in Table III. The relation $n_j\simeq\sum S_{jk}$ is assumed where n_j is the number of protons in shell orbit j.

V. DISCUSSION

A. Interpretation of (d, ^{3}He) Data

It is immediately evident from Table I that all the low-lying ^{46}Sc levels owe appreciable parentage to the complex $(f_{7/2}{}^{7})_{5/2}$ ground-state configuration of ^{47}Ti. In the adjacent column is shown the ^{45}Sc(d, p)^{46}Sc spectroscopic factors of Ref. 1 with the $(2J_j+1)/(2J_i+1)$ factors removed according to the J^{π} values in the far right column. The significance of the comparison is that the target for the (d, ^{3}He) studies contains no lowest ($\nu=1$) seniority for the $7f_{7/2}$ nucleons, whereas the (d, p) target ^{45}Sc is expected to be mostly a lowest seniority state.[16] The moderate spectroscopic factors for 1=3 transitions in both (d, p) and (d, ^{3}He) reactions is evident that mixing within the ($f_{7/2,}$) configurations is a more significant aspect of the lower-lying ^{46}Sc states than mixing between the $1f$ and $2p$ orbitals. The sum rule from Table III for the proton occupation of the $2p_{(3/2)}$ orbit indicates only $\lesssim 5\%$ fullness.

It appears from Table III that the $f_{7/2}$ shell of ^{47}Ti is in slight excess of the zero-order shell-model value of two protons. The lack of fullness for the $2s_{1/2}$ orbit is probably within the experimental uncertainty owing to the small cross sections expected for higher states in the spectrum. On the other hand, the fullness of the $d_{3/2}$ orbit is approximately 70%. Only about 10% of this loss seems to arise from a proton excess in the $f_{7/2}$ shell, and the remaining $d_{3/2}$ strength ($\approx 20\%$) is apparently[17] scattered into higher excitation ^{46}Sc states not observed in this work. In spite of some unobserved $2s_{1/2}$, $1d_{3/2}$, and possibly $1f_{7/2}$ strength, the relative center-of-gravity calculations should be approximately correct, and they indicate closer single-proton orbit spacing for ^{47}Ti compared to ^{48}Ti.

[13] R. H. Bassel, Phys. Rev. **149**, 791 (1966).
[14] E. Newman and J. C. Hiebert, Nucl. Phys. **A110**, 366 (1968).
[15] The range R is defined differently by a factor of 2 in Ref. 13 and in the code DWUCK (Ref. 10).
[16] J. D. McCullen, B. F. Bayman, and L. Zamick, Phys. Rev. **134**, 515 (1964).
[17] Isotopic spin is assumed to be a valid quantum number (i.e., $C^2=1$ for proton pickup). T mixing would also result in a deficiency for proton pickup strength to low-lying levels.

TABLE III. Properties of the proton "shells" in the target nucleus according to the spectroscopic strengths observed in this work. The first and second columns identify the nucleus and shell orbit. The third and fourth columns contain the sums of spectroscopic strengths found in columns 3 and 4 of Table I. The fifth column shows the sum rules found when the finite range and nonlocality parameters of Table II are used. The sixth column contains the zero-order shell model estimate for $n=\Sigma S$, and the seventh column indicates the resulting center of gravity of the d and s orbits relative to the f. The value 1.40 for $2s_{1/2}$ in ^{48}Ti is from Refs. 14 and 5.

Target	nlj	ΣS^z	ΣS^i	ΣS^b	ΣS^{Th}	$\langle E_x \rangle$ (MeV)
^{47}Ti	$2p$	0.22	0.18	0.13	0.0	···
^{47}Ti	$1f_{7/2}$	2.88	2.35	1.84	2.0	0.000
^{47}Ti	$1d_{3/2}$	3.52	2.82	2.04	4.0	0.490
^{47}Ti	$2s_{1/2}$	2.02	1.57	1.10	2.0	0.780
^{48}Ti	$1f_{7/2}$	2.4	2.0	1.6	2.0	0.000
^{48}Ti	$1d_{3/2}$	4.9	4.0	2.9	4.0	0.764
^{48}Ti	$2s_{1/2}$	···	···	···	···	≈1.40

B. Comparison with Other Studies

The proposed proton excess in the $f_{7/2}$ shell and corresponding deficiency in the $d_{3/2}$ orbit should be evident from proton-stripping reactions. This, in fact, seems to be the case both from the reactions[18,19] $^{46}Ti(^3He, d)^{47}V$ and $^{48}Ti(^3He, d)^{49}V$ in which an approximately 10% vacancy for the $d_{3/2}$ shell was measured. Proposed proton excess in the $2p$ shell is qualitatively consistent with the $^{48}Ti(d, \alpha)^{46}Sc$ study[4] in which the low-lying natural-parity levels 4^+ and 2^+ were weakly excited. In addition, the excitation of the 6^+ level[4] led to the conclusion that the $f_{5/2}$ shell was not empty in ^{48}Ti although the present study is not expected to confirm this.

Since the (d, α) reaction should excite only the lowest-seniority component of the ^{46}Sc states, it is of interest to compare the relative strengths of this reaction with the present work. There are three 5^+ states (0.280, 0.774, and 0.835 MeV) below 0.9-MeV excitation proposed by the (n, γ) studies.[2] Only one (the 0.282-MeV level) is strongly excited in $(d, ^3He)$ and only one (the 0.774-MeV level) is strongly excited in (d, α). The marked weakness and l purity of the (d, α) transfer to the 0.835 level would favor a natural parity assignment of 4^+ rather than 5^+. The lowest 1^-, 3^-, and 4^- levels are strongly excited only in $(d, ^3He)$. On the other hand, strong negative-parity transitions in (d, α) involving $d_{3/2}$ and $2s_{1/2}$ protons with $f_{7/2}$ neutrons appear to excite states as high as 1.648 and 2.788 MeV. The conclusion from the above comparison is that the averaging binding energy of the more highly paired valence nucleons is sometimes less than the average binding energy for the largely unpaired valence nucleons. The difference in these average binding energies is, however, not large, and this fact does much to explain the nature of the high bound-state level density in ^{46}Sc as well as the marked configuration mixing.

Difficulties brought by comparing the $(d, ^3He)$ with the (d, α) work should also be noted: (a) The lowest positive-parity states in ^{46}Sc are much more "nucleon unpaired" than originally believed in Ref. 4, and this complicates shell-model intensity rules for the (d, α) reaction. (b) The 1.268-MeV level is strongly excited by $2s_{1/2}$ proton pickup in $(d, ^3He)$ and must be J^π 2^- or 3^-. The (d, α) is weak as expected, but appears to be dominated by $L=5$, indicating $J^\pi=4^-$, 5^-, or 6^-. Excitation-energy uncertainties for the two reactions would allow for a possible doublet here.

Although a fully consistent set of wave functions are not available for ^{46}Sc at this time, some comments regarding the MBZ solutions[16] for the $(f_{7/2})^6$ positive-parity states can be made. One must first lower the excitation of the 1^+ and 7^+ MBZ states in order to get the correct number of positive-parity states in the first MeV of excitation. The MBZ spin values can then be matched one to one with those in Table I provided the 4^+ value is taken for the 0.833-MeV level. One then finds qualitative agreement with respect to the level ordering except for an inversion of the near-degenerate 4^+ ground state and the 6^+ level. The spectroscopic factors for (d, p) are then in fair agreement with MBZ except for the 5^+ levels which are again inverted with wave-function admixtures apparently too large to account for either the $(d, ^3He)$ or (d, p) results. In the MBZ formalism one expects a spin dependence for the $(d, ^3He)$ spectroscopic factors giving rise to generally larger values for higher spin states. This is qualitatively supported in the measurements shown in Table I.

ACKNOWLEDGMENTS

The author is grateful to Dr. W. W. Daehnick, Dr. R. H. Bassel, and Dr. J. Rapaport for helpful discussions throughout this project, and to M. Schneider for assistance in the data acquisition.

[18] W. E. Dorenbusch, J. Rapaport, and T. A. Belote, Nucl. Phys. **A102**, 681 (1967).

[19] D. Bachner, R. Santo, H. H. Duhm, R. Bock, and S. Hinds, Nucl. Phys. **A106**, 577 (1968).