Investigation of Configurations in Sc^{46} by the Direct $Ti^{48}(d, \alpha)Sc^{46}$ Reaction*

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The angular distributions from the $Ti^{48}(d, \alpha)Sc^{46}$ reaction have been measured at a deuteron beam energy of 17 MeV. The α particles were analyzed primarily by position-sensitive counters mounted in an Enge split-pole spectrograph with a typical experimental resolution of 15 keV full width at half-maximum for 20-MeV α particles. Distorted-wave Born-approximation calculations utilizing a microscopic form factor and including finite-range and nonlocal corrections produced reliable deuteron l-transfer distribution shapes. The experimental distributions indicate many unambiguous l transfers which determine parity and restrict possible J values for final states in Sc^{46}. The relative strengths of the cross sections are subject to configuration effects through the $2s$, $1d$, $1f$, and $2p$ nucleons which form the deuteron in the pickup process. In particular, states excited by $(f_{7/2})^2$, $(d_{3/2}f_{7/2})$, and possibly $s_{1/2}f_{7/2}$ and $(d_{3/2})^2$ pickup were identified. Of special interest is the population of the low-lying 6^+ state in Sc^{46}, which can be quantitatively understood in terms of a $\approx 1\%$ occupation probability for nucleons in the $1f_{5/2}$ shell of Ti^{48}.

I. INTRODUCTION

THE low-lying levels of Sc^{46} have previously been investigated by the $Sc^{45}(d, p)Sc^{46}$ and $Ti^{47}(d, He^3)Sc^{46}$ reactions.[1,2] In the latter reaction, the experimental resolution was not sufficient to resolve individual levels, and only an estimate of the excitation region of $d_{3/2}^{-1}$ strength could be made. In the stripping reaction below 3-MeV excitation, 54 levels were excited and many l_n-value assignments made. However, in reaching the odd-odd Sc^{46} states by the single nucleon transfer reactions above, the odd-A target ground state has a high spin of $\frac{7}{2}$ or $\frac{5}{2}$ and l-values hardly restrict possible final-state spin values. Also, the uncertain seniority configurations in the target ground state severely complicate interpretation of the transition intensities.

The levels of Sc^{46} in the first MeV excitation region have also been investigated by the $Sc^{45}(n, \gamma)Sc^{46}$ reaction.[3,4] Many probable spin assignments were made based on primarily upon dipole transition assumptions. Transition speeds were also estimated. Evidence for several negative-parity states was confirmed, the first one as low as 141-keV excitation. Thus, the previous studies of Sc^{46} have identified the low-lying levels but have produced little information for the configurations or spin values above 1 MeV.

That significant information pertaining to nuclear configurations can be obtained by the study of two-particle transfer reactions was pointed out by Bayman,[5] Glendenning,[6] and others several years ago. More recently Daehnick and Park[7] have shown that the angular distributions from the (d, α) reaction on even-Zn isotopes at 12 MeV are quite characteristic of the spin and parity of the final state, and can be predicted by distorted-wave Born-approximation (DWBA) codes without subjective parameter fitting of the nuclear geometry. Thus both spectroscopy and configurations (especially of the neutron-proton hole type) of odd-odd nuclei can be investigated by the direct (d, α) reaction.

It is experimentally well known that in filling the $1f_{7/2}$ shell ($A \approx 40$–50 nuclei), the $1d_{3/2}$-$1f_{7/2}$ "single-particle" energy separation quickly diminishes to less than 1 MeV in some cases. A similar situation is true for $2s_{1/2}$-$1f_{7/2}$ separation.[2,8,9] This fact implies low-lying negative-parity configurations in Sc^{46} of the type $1d_{3/2}^{-1}, f_{7/2}{}^7$ and $2s_{1/2}^{-1}, f_{7/2}{}^7$ coupled to a Ca^{40} core. In the case of the $Ti^{48}(d, \alpha)Sc^{46}$ reaction, in addition to $f_{7/2}{}^6$ states, these nucleon-nucleon hole configurations would be strongly excited. Also important is that by reaching Sc^{46} from an even-even ($J^\pi = 0^+$) target, the l transfer more strictly selects the spin parity of the Sc^{46} states, while the seniority of zero for Ti^{48} ground state makes it easier to interpret the intensities of the cross sections.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

Ti^{48} films of 20–100 $\mu g/cm^2$ were prepared by electron-gun evaporation of titanium metal with isotope-48 purity of about 97%. The Ti vapor condensed on a 20 $\mu g/cm^2$ carbon film and was mounted on a target frame with a 0.5-in.-high and 0.25-in.-wide aperature. The targets were checked for uniformity and thickness by exposing them to a deuteron beam at 11.8 MeV and detecting elastic particles with a position-sensitive detector mounted in an Enge split-pole spectrograph with the entrance aperature set at the same value as that

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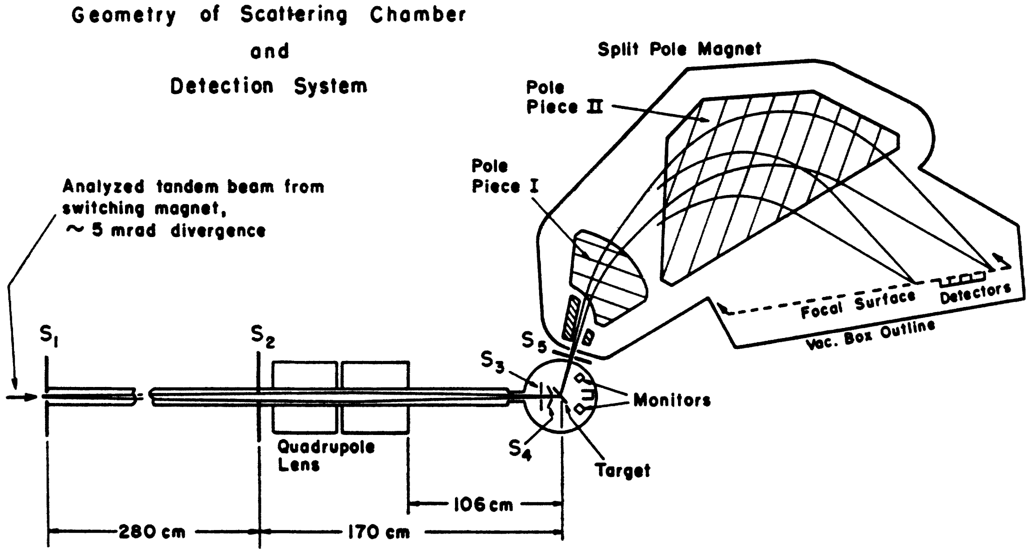

FIG. 1. Sketch of the experimental setup showing the incident beam path and the reaction product trajectories to the position detectors at the focal surface of the magnet.

used in the reaction study, $\Omega=1.4\times10^{-3}$ sr. Poor uniformity would result in a broadening of the elastic peak. The thickness was computed by comparing the count rate/charge collected with known cross-section measurements.[10] A target of 36 μg/cm^2 was chosen.

The experimental set up is similar to that described in detail in Ref. 11, so only the most essential points will be given below.

The $Ti^{48}(d,\alpha)Sc^{46}$ reaction was investigated with a deuteron beam energy of 17.0 MeV. The beam currents from the University of Pittsburgh three-state tandem Van de Graaff were typically $\sim$0.5 μA on the Ti target except for the most forward angles. A beam spread of $\Delta E\approx 2$ keV was maintained. A quadrupole lens positioned 106 cm upstream from the target focused the beam to about 0.5 mm in width, 2 mm in height, and with a horizontal divergence of about 12×10^{-3} rad. The collimating slit 0.5 mm wide and 2 mm high was positioned about 1 cm before the target, followed by an antiscattering collimator. A sketch of the experimental set up is shown in Fig. 1.

The α particles were detected by an array of four position-sensitive counters mounted in an Enge split-pole magnetic spectrograph. The entrance aperature to the spectrograph subtends a 1.4-msr solid angle to the target. Each detector has a sensitive region 8 mm high and 40–50 mm in length. There are, of course, gaps between successive detectors corresponding to energy regions of about 180 keV. Thus, in order to take complete spectra, one must take data at two slightly different magnetic field setting for each angle. The spatial resolution of the position counters was $\sim$1% which corresponds to $\sim$10 keV full width at half-maximum (FWHM) for 20 MeV α particles observed in this work.

Figure 2 shows a block diagram of the electronic circuitry used in the acquisition of the α spectra. A fixed NaI scintillation counter mounted in the target chamber was used to monitor the incident beam for normalization of points in the angular distribution. At any given position on the focal plane the α particles are distinguishable from deuterons in that the α energy is twice that of the deuterons. Protons have the same energy as the alphas but deposit only a fraction of their energy as they readily pass through the 500-μ-thick Si triode counters. The position counters then yield two signals: (a) the net energy (E) deposited in the counter, (b) the product of this energy and the relative position at which the particle strikes the counter (XE). The former signal was used for particle-type discrimination. The XE signal was used for the α-momentum measurement and was routed and stored in four memory banks (corresponding to the four detectors) in a 4×1024-channel analyzer. The E signal can be used as an input to a fixed level discriminator or as a continuous parameter in conjunction with XE for a two-parameter ($XE\times E$) array. For all angles except 30° the former method was employed.

Data were taken in 5° steps from 15° to 90° as well as a point at 12°. For the 20°, 15°, and 12° points the collimating slit was increased to 1 mm and the counter bias lowered to increase the α/deuteron count ratio. Position-sensitive counters with optimum spatial resolution have an inherent nonlinearity in both signals. This makes energy calibration difficult, so that in this

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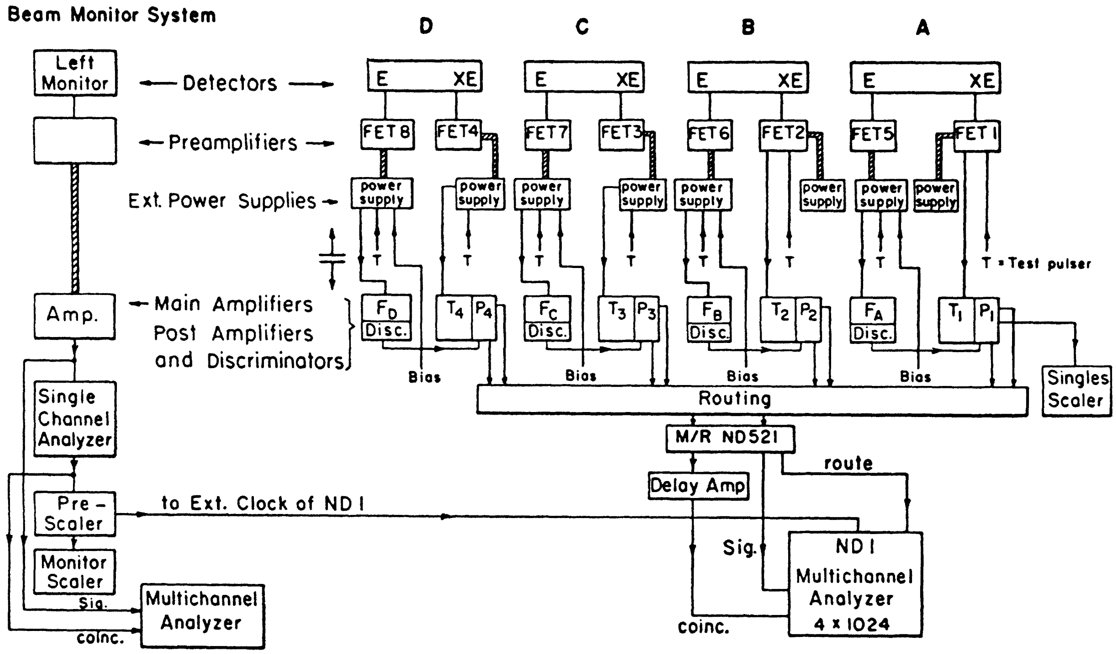

FIG. 2. Block diagram of a typical electronic network for use with position-sensitive counters A, B, C, and D. The circuit routes and stores the position×energy product (XE) without division of XE by E.

experiment two additional runs were made at 40° and 50° in which the counters were replaced by Ilford K-1, 50-μ photographic plates. Peaks were then calibrated in excitation energy with the code SPECTRE.[12] Typically about 1000 μC of charge was collected for forward angles while about 4000 μC was collected for the largest angles.

Prior to the spectrograph run, an angular distribution was taken with silicon barrier detectors in a conventional scattering chamber in order to have a second normalization check for the position-counter data. Only large well-isolated peaks could be analyzed from this 40-keV resolution data. The spectrograph data were then taken at only one magnetic current setting (frequency) for each angle (except 15° and 30°). At such a setting the peak at ~980-keV excitation, which could be analyzed with the conventional counter data, was purposely placed between the first two position counters.

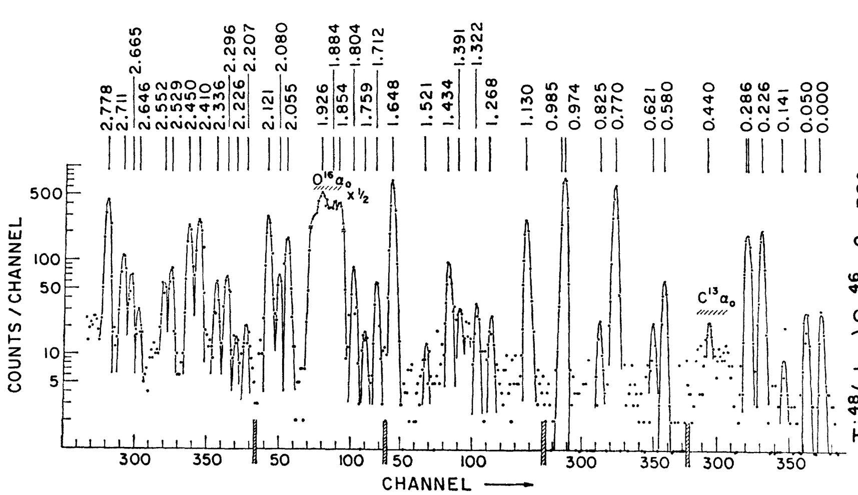

FIG. 3. Typical three-position counter α-particle spectrum (θ_L= 30°). All peaks refer to scandium levels except C^{13} α_0 and O^{16} α_0 as indicated. This spectrum was taken at two spectrograph field settings and pieced together at the indicated junctions along the channel numbers. See text for experimental error.

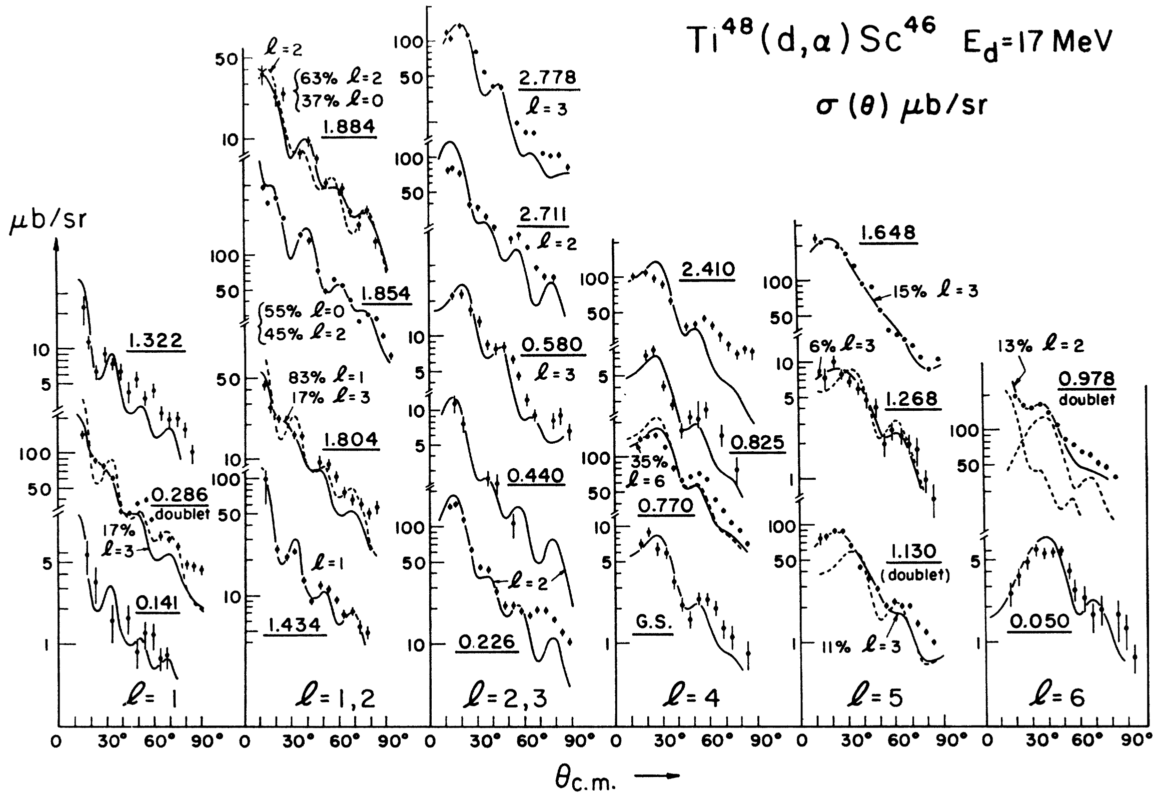

FIG. 4. Angular distributions for the $Ti^{48}(d,\alpha)Sc^{46}$ reaction at 17 MeV. The curves shown are from DWBA analysis. The curves are then grouped by l value as indicated See text for a discussion of experimental error.

Thus nearly all the α groups of interest could be analyzed without running the experiment at two frequencies. All α groups examined in this work ($E_x<2.8$ MeV) could be found on the first three position counters and only a few between the second and third counters were missed in the experiment.

III. EXPERIMENTAL RESULTS

The position counter spectrum at 30° (taken at two magnetic current settings) is shown in Fig. 3. Typical experimental resolution with the position counters was 15-keV FWHM for $\sim$20 MeV α-particle groups. The spatial resolution of the counters and the finite target thickness were the principal contributiors to the experimental resolution. The peak-to-valley ratio was about 500/1 for strong α groups. Although only the region below 2.8-MeV excitation was investigated, the photographic plate exposures indicated no strong (or resolved) groups existed in the 3–8 MeV excitztion region. α groups from the $O^{16}(d,\alpha)N^{14}$ and $C^{13}(d,\alpha)B^{11}$ reactions were contaminants in the Sc^{46} groups. The level density in Sc^{46} is quite high, as can be seen in Fig. 3, so that by statistical arguments alone it is likely that there are doublets not resolved in the spectrum.

The angular distributions for most of the α groups are shown in Fig. 4. The distributions are grouped according to dominant l transfer. The curves through the data points are from DWBA predictions and are explained in Sec. IV. The excitation of the final states in Sc^{46} are underlined numbers in the figure. Groups likely to be two unresolved groups are indicated as "doublet." All distributions are from the position counter data except the 0.978-MeV group, which was extracted from the conventional counter data. The 0.770-MeV group was

TABLE I. Values of optical-model parameters chosen from Ref. 14 in usual notation. W and W' refer to imaginary volume and surface potentials.

Channel	V_0 (MeV)	r_0 (F)	a (F)	r_c (F)	W (MeV)	W' (MeV)	r_I (F)	a_I (F)
d	74.0	1.329	0.710	1.329	0.00	20.33	1.333	0.645
α	169.8	1.445	0.494	1.30	25.1	0.00	0.00	0.00

carefully compared with the conventional counter data and found to be in good agreement.

The experimental uncertainties in assignment of excitation energy are ±6, ±8, and ±10 keV for the 0–1, 1–2, and 2–3 MeV excitation region, respectively. The relative differential cross-section errors are shown in Fig. 4. Not shown in the figure is the absolute cross-section error which enters through uncertainties in target thickness and charge collection and this is estimated at 20%.

IV. ANALYSIS OF CROSS-SECTION DATA

The experimental angular distributions were compared with DWBA predictions. Details of the application of distorted-wave calculations to d, α reactions are summarized in Ref. 7. The DWBA code DWUCK[13] was employed in this work. Nonlocal and finite-range parameters of $\beta_d=0.54$, $\beta_\alpha=0.2$, and $R_{d.\alpha}=0.4$ were used. Optical-model parameters were chosen from Ref. 14 and given in Table I.[15] The deuteron form factor was computed on a microscopic basis by the method and code of Drisko and Rybicki.[16] The overlap between the true microscopic form factors and the one used in this work was always better than 96%. For positive-parity (l even) transfers, the microscopic basis was taken as two $1f_{7/2}$ nucleons and for negative-parity (l odd) transfers, one $1d_{3/2}$ and one $1f_{7/2}$. The Woods-Saxon well geometry was the usual $r_0=1.25$ F and $a=0.65$ F, with the depth adjusted to give the correct deuteron binding energy.

The results of the theoretical angular-distribution shapes are shown as arbitrarily normalized curves in Fig. 4. In cases where two l values are believed mixed into one state, the dominant l transfer is shown as a broken curve. The positions of maxima and minima are distinctly predicted by the DWBA, so that little ambiguity remains in assigning an l transfer to the data The relation between the l transfer and the spin and parity of the Sc^{46} states is shown in Table II.

The special significance of the intensities for the (d, α) transitions can be illustrated by examining the deuteron form factor[6,7]

$$F_{LSJT}(R)=\sum_{\gamma}\beta_{\gamma LSJT}f_{L\gamma}(R),$$

with

$$f_{L\gamma}(R)=\sum_{N}g_{NL\gamma}U_{NL\gamma}(R). \qquad (1)$$

The quantum numbers of the transferred nucleon pair are the L, S, J, and T ($L\equiv l$ transfer) while R and N refer to its c.m. motion and γ to one of the $[j_1 j_2]_J$ nucleon pair configurations. For the Ti^{48} target $J=J(Sc^{46})$, and $L\equiv l$ above. $U_{NL\gamma}(R)$ is the component of the two-nucleon radial wave function with amplitude $g_{NL\gamma}$. The $f_{L\gamma}(R)$ is generated by the Drisko-Rybicki code and one is referred to Ref. 16 for details. The nuclear-structure effects enter primarily through the spectroscopic amplitude $\beta_{\gamma LSJT}$. For remaining discussions this amplitude will be parametrized in quasi-particle notation,[6,17] i.e.,

$$\beta_{\gamma LSJT}=(2J+1)^{1/2}V_{J_1}V_{J_2}\begin{Bmatrix} l_1 & \frac{1}{2} & j_1 \\ l_2 & \frac{1}{2} & j_2 \\ L & S & J \end{Bmatrix}\delta_{T,0}, \qquad (2)$$

where V_j is the occupation probability amplitude for orbit j in the target nucleus ground state, and the bracket is the LS-jj transformation bracket.

Two important selection rules follow from the symmetry of the bracket[6,18]: (a) The bracket vanishes when $J^\pi(Sc^{46})=0^+$ since we assume a triplet deuteron transfer ($S=1$); (b) the bracket vanishes when j_1 and j_2 are equivalent orbits (e.g., $j_{1/2}=f_{7/2}$) and J is even (e.g., 0, 2, 4, or 6), regardless of seniority in the target nucleus. In addition, the V_j for $j=j_>$ (i.e., above the $f_{7/2}$ shell) are known to be small in Ti^{48}.[9] Finally, configurations with more than two unpaired nucleons will hardly be seen due to the nearly pure seniority $(\nu)=0$ ground state of the even-even target nucleus.

One then investigates the configurations in Sc^{46} by looking for the following:

(a) relatively strong (weak) positive-parity $l=0$, 2, 4, 6 transitons in the lowest excitation region—expected for dominating $(1f_{7/2}{}^2)J=$ odd (even) deuteron pickup amplitudes;

(b) relatively strong negative-parity $l=1$, 3, 5 transitions in the lowest excitation region—expected for dominating $(d_{3/2}f_{7/2})J=$ even or odd pickup;

(c) relatively strong positive-parity $l=0,2,4$ transitions in higher excitation regions, implying $(d_{3/2}{}^2)J=$ odd or $(s_{1/2}d_{3/2})J=$ even or odd pickup; and

(d) relatively strong negative-parity $l=3$ transitions in higher excitations regions suggesting $(s_{1/2}f_{7/2})J=$ even or odd pickup.

TABLE II. Spectroscopic rules applicable to the direct $Ti^{48}(d, \alpha)$ Sc^{46} reaction (from Ref. 6)

l transfer	Parity	J value
even	+	$J_{even}=l$
		$J_{odd}=l\pm1$
odd	−	$J_{odd}=l$
		$J_{even}=l\pm1$

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TABLE III. Summary of excitation energies of states seen in the $Ti^{48}(d,\alpha)Sc^{46}$ reaction followed by relative transition strengths and angular momentum transfers populating the Sc^{46} levels with spin parity J^π and suggested major configurations about the Ca^{40} core. Less certain l and J^π values are placed in parentheses. Excitation energy errors are given in the text.

Excitation	Relative 30° strength	l transfer	J^π	Suggested major config.
ground state	1.0	4	4^+	$f_{7/2}^6$
0.050	1.1	6	6^+	$f_{7/2}^6$
0.141	0.3	1	$0^-, 1^-, 2^-$	$d_{3/2}^{-1}, f_{7/2}^7$ $(\nu=3)$
0.226	7.8	2	$3^+(1^+, 2^+)$	$f_{7/2}^6$ $(\nu=2)$
0.286	10.0	1+(3)	2^-	$d_{3/2}^{-1}, f_{7/2}^7$ $(\nu=1)$
0.440	0.5	2	$2^+(1^+, 3^+)$	$f_{7/2}^6$
0.580	2.3	3	$3^-(2^-, 4^-)$	$d_{3/2}^{-1}, f_{7/2}^7$ $(\nu=1+\nu=3)$
0.621	0.7	(3+5)	(4^-)	$d_{3/2}^{-1}, f_{7/2}^7$ $(\nu=3)$
0.770	20.9	4+(6)	$5^+(3^+, 4^+)$	$f_{7/2}^6$ $(\nu=2)$
0.825	0.7	4	$3^+4^+5^+$	$f_{7/2}^6$
0.974	27.0	6	7^+	$f_{7/2}^6$ $(\nu=2)$
0.985	6.0	2+(0)	$1^+(2^+3^+)$	$f_{7/2}^6$ $(\nu=2)$
1.130	11.4	5+3	4^-	$d_{3/2}^{-1}, f_{7/2}^7$ $(\nu=1)$
1.268	1.7	5+(3)	$4^-, 5^-, 6^-$	$d_{3/2}^{-1}, f_{7/2}^7$ $(\nu=3)$
1.322	1.3	1	$0^-1^-2^-$	
1.391	1.0	(3)	$3^-(4^-5^-)$	
1.434	4.1	1	$0^-, 1^-, 2^-$	
1.521	0.4	(3, 4)	(>3)	
1.648	28.8	5+(3)	$5^-, 4^-$	$d_{3/2}^{-1}, f_{7/2}^7$ $(\nu=1)$
1.712	3.0	(1+3)	(2^-)	
1.759	0.8	...		
1.804	2.8	1+(3)	(2^-)	
1.854	(17)	0+2	1^+	$d_{3/2}^{-2}$ $(\nu=2)$, $f_{7/2}^8$ $(\nu=0)$
1.884	(1.4)	2(+0)	$1^+(2^+, 3^+)$	
1.926	0.6	...	...	
2.055	8.1	...	...	
2.080	2.5	(2)	...	
2.121	12.8	...		
2.207	0.9			
2.226	0.5			
2.296	3.8			
2.336	2.0			
2.410	15.2	4	$3^+4^+5^+$	$d_{3/2}^{-2}$ $(\nu=2)$, $f_{7/2}^8$ $(\nu=0)$
2.450	10.7	(4)	$(3^+4^+5^+)$	
2.529	3.8	...		
2.552	1.8	...		
2.646	1.1	...		
2.665	2.9	...		
2.711	6.3	2	$2^+1^+3^+$	$s_{1/2}^{-1}, d_{3/2}^{-1}, f_{7/2}^8$ $(\nu=0)$
2.778	15.0	3	$4^-3^-(2^-)$	$s_{1/2}^{-1}, f_{7/2}^7$ $(\nu=1)$

Of course, the strong transitions should show approximate relative strengths as suggested by Eqs. (1) and (2).

V. DISCUSSION OF Sc^{46} LEVELS

A summary of the results of the reaction data is presented in Table III. The excitation energy and cross-section strength are relative to the ground state of Sc^{46}. The suggested J^π and dominant configuration is based primarily upon this work unless otherwise noted below.

A. $f_{7/2}^6$ ($\nu=2$) Configurations

Below 1 MeV weak but apparently pure $l=2$, 4, 6 transitions to 0.440-, 0.000-, and 0.050-MeV Sc^{46} states and comparatively strong $l=2+(0)$, 2, $4+(6)$, and 6 transitions to 0.985-, 0.226-, 0.770-, and 0.974-MeV states is strong evidence for dominating $f_{7/2}^6(\nu=2)$ final-state wave functions. A more quantitative illustration of this is given in Fig. 5. All theoretical intensities based on the prescription in Sec. IV have the same, however arbitrary, normalization. The experimental intensities are one-half the value in Table III, column 2. It is noteworthy that the $J=$even strengths are consistently weaker by more than an order of magnitude from neighboring $J=$odd states. This is consistent with the direct deuteron-transfer assumption. Also the strong $J=$odd states have nearly the expected relative transition strength. The spin and parity of these Sc^{46} states were deduced from the d, α analysis of $f_{7/2}^2$ transitions. The only inconsistency with previous investigations[1–4] is that the γ transitions appear to bypass the 7^+ state, perhaps due to its high spin, and the (d, p) investigation does not report the 1^+ state, apparently due to its relatively small cross section and proximity to the 7^+ state.

B. $d_{3/2}^{-1}$, $f_{7/2}^7$ ($\nu=1$) Configurations

Strong [i.e., comparable to $(f_{7/2}^2)J=$odd] negative-parity transitions can be seen to populate the low-lying

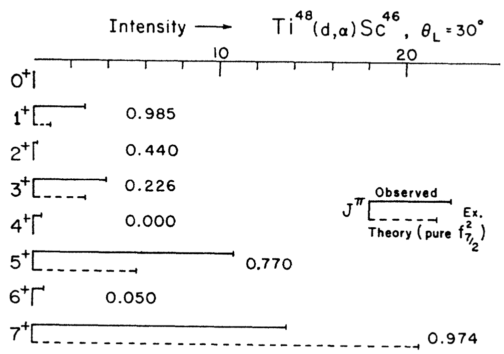

FIG. 5. Comparison of experimental and theoretical intensities. The relative experimental cross sections populating levels believed to be of primarily $f_{7/2}^6(\nu=2)$ configuration are shown by the solid lines with spin and excitation energy indicated. The broken lines represent the intensity distribution expected from a direct deuteron pickup process consisting of two $f_{7/2}$ particles. The theoretical intensity vanishes for $J=$even states (see Sec. IV).

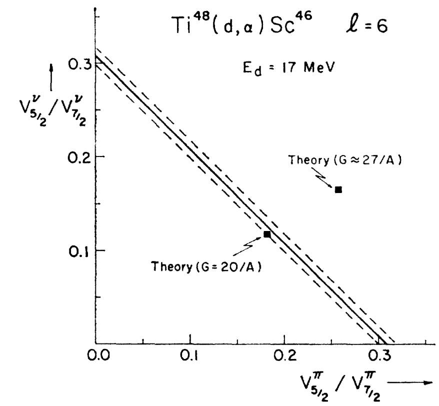

FIG. 6. Relative occupation probability for the $1f_{5/2}$ particle orbit in Ti^{48} indicated by the population of the 6^+ level of Sc^{46} in the direct $Ti^{48}(d, \alpha)Sc^{46}$ reaction. The experimental uncertainty is shown by the broken lines. The theoretical estimates are from pairing-theory calculations (Ref. 19).

0.286- and 1.130-MeV states of Sc^{46}. The l mixtures indicate $J^\pi=2^-$ and 4^-, respectively. However, no strong $l=3$ transition leading to the $J^\pi=3^-$ member of $d_{3/2}^{-1}f_{7/2}^7$ can be seen below 2 MeV. Also, the $l=5$ transition to the 1.648-MeV state, which has the approximate intensity expected for the $J=5$ member, appears to have $l=3$ admixture.

C. Configurations at Higher Excitation

The intense $l=0+2$ transition at 1.854 MeV is evidence for the $d_{3/2}^{-2}(\nu=2)$, $f_{7/2}^8(\nu=0)$, $J=1$ configuration due to its $l=0$ strength, and excitation energy. The strong $l=4$ transition to the 2.410-MeV level is expected for the $J=3$ member. For $s_{1/2}^{-1}$ $d_{3/2}^{-1}$ transitions only $l=2$ is allowed by the transformation bracket of Eq. (2) and for $s_{1/2}^{-1}f_{7/2}^{-1}$ only $l=3$. For this reason, the 2.711- and 2.778-MeV levels have been assigned as predominantly $s_{1/2}^{-1}d_{3/2}^{-1}f_{7/2}^8(\nu=0)$ and $s_{1/2}^{-1}$, $f_{7/2}^7(\nu=1)$, respectively.

D. Other Configurations

The spectrum of Sc^{46}, even below 1 MeV, is of formidable complexity. There are several levels which are very weakly seen in (d, α) and (d, p) and yet lie very low in excitation. Some of these states (0.141, 0.580, and 0.621 MeV) may have neutron seniority $\nu_n=3$ since they do appear relatively strong in the $Ti^{47}(d, He^3)Sc^{46}$ reaction[2] in which the target ground state ($j=\frac{5}{2}$) is believed to be predominately $f_{7/2}^7(\nu_n=3)$.[19] The population in Sc^{46} of the J^+ even states, e.g., the ground state, mentioned in Sec. V A is consistent with the few percent occupation strength expected of the $2p_{3/2}$, $2p_{1/2}$, and $1f_{5/2}$ orbitals in Ti^{48}, so that configurations of all predominantly $f_{7/2}^6$ states surely include minor admixtures of $(2p_{3/2}f_{7/2}^5)$, $(2p_{1/2}f_{7/2}^5)$, and $(f_{5/2}f_{7/2}^5)$, where allowed by angular momentum conservation.

[19] J. D. McCullen, B. F. Bayman, and Larry Zamick, Phys. Rev. **134**, B515 (1964).

VI. SIGNIFICANCE OF EXCITING THE 6^+, 0.050-MeV LEVEL

As a result of J = even selection rule discussed in Sec. IV, the only direct one-step process allowed for exciting the 6^+ level in Sc^{46} is the pickup of $(f_{7/2}f_{5/2})$ nucleon pairs. On the other hand, the excitation of the 7^+, 0.974-MeV level is possible only via $(f_{7/2}{}^2)$ pickup. This allows a very sensitive check as to the relative probability for occupation of the $f_{5/2}$ orbital. To illustrate this quantitatively recall from Sec. IV that the radial amplitude $f_{L\gamma}(R)$ for each of the above processes is quite similar, being generated from two $l=3$ orbits with similar binding energies for the cluster deuteron. The square root of the ratio (r) of the cross sections for the 6^+ to the 7^+ Sc^{46} states can be approximated by

$$r^{1/2}=\sum_{\gamma'}\beta_{\gamma'}(6^+)/\sum_{\gamma}\beta_{\gamma}(7^+). \quad (3)$$

In the quasiparticle approximation of initial and final states, the root ratio reduces [from Eq. (2)] to

$$r^{1/2}=\frac{(\sqrt{13})(V_{7/2}{}^{\pi}V_{5/2}{}^{\nu}+V_{5/2}{}^{\pi}V_{7/2}{}^{\nu})\,[J=6]}{(\sqrt{15})\,V_{7/2}{}^{\pi}V_{7/2}{}^{\nu}\,[J=7]}, \quad (4)$$

where the transformation bracket is abbreviated $[J]$ and superscripts π,ν refer to the proton and neutron orbits. In its simplest form Eq. (4) reduces to

$$r^{1/2}\simeq 0.66(V_{5/2}{}^{\nu}/V_{7/2}{}^{\nu}+V_{5/2}{}^{\pi}/V_{7/2}{}^{\pi}). \quad (5)$$

The ratio measured in this work is $r=0.041\pm0.004$. It is then possible to graph from Eq. (5) the limits of the relative $1f_{5/2}$ occupancy as shown in Fig. 6 by the region between the broken lines.

The reasonableness of this approach can be demonstrated by using for $V_{5/2}{}^{\pi}(Ti^{48})(Z=22)$ the value of $V_{5/2}{}^{\nu}(Ca^{42})$, and for $V_{5/2}{}^{\nu}(Ti^{48})(N=26)$ the value of $V_{5/2}{}^{\nu}(Ca^{46})$, where the nucleon numbers have been estimated for calcium by Bayman and Hintz[20] for two possible pairing strengths G. The values for $V_{7/2}$ are nearly the shell-model of $(\frac{1}{8}n)^{1/2}$, where n is the nucleon number outside the Ca^{40} core. The pairing-model values are indicated in Fig. 6. However, it is not the purpose of this discussion to evaluate the calculations in Ref. 20, but to emphasize the potential sensitivity of the deuteron transfer reaction to occupation probabilities. Of course, the above analysis is approximated by the assumption of a *one*-step reaction mechanism and a quasiparticle description of initial and final states.

[20] B. F. Bayman and N. M. Hintz, Phys. Rev. **172**, 1113 (1968).

VII. CONCLUSIONS

The result of the (d,α) study was to help to identify many levels in Sc^{46} through their characteristic or predominant two-nucleon configuration. The population of the low-lying J^+ even states, especially the 6^+, strongly suggests that many configurations are present in the low-lying Sc^{46} levels. With few exceptions it is unlikely that, in view of experimental resolution and error, the levels excited via (d,α) are different than those reported in the (d,p) studies. Thus, the activity of at least the $1f_{7/1}$ nucleons is such that it is entirely unclear what one would identify as an inert nuclear core even in this "magic-number" region. If the Sc^{46} data are to be analyzed realistically on a shell-model basis, it is clear that a very large model space must be assumed, and that Ca^{40} cannot be taken as merely an inactive nuclear core.

It should be emphasized that considerable information concerning Sc^{46} (as well as most odd-odd nuclei) will be lost in modest resolution experiments. Even the 15-keV resolution present in this work was inadequate to resolve several levels, for example, the doublet at 280–289 keV reported in Refs. 3 and 4. Thus the $l=3$ admixture shown in Fig. 4 for the 0.286-MeV level may be the effect of the weaker member of the doublet. The γ-transition data of Ref. 3 also indicate two doublets with members separated ≤ 8 keV at about $E=1.40$ and 1.43 MeV. It is here also that the (d,α) and (d,p) data assign different parities. Thus, inconsistencies in the Sc^{46} data are very likely due to the high level density. Clearly, it would be of value to repeat the $Ti^{47}(d,He^3)Sc^{46}$ reaction with $\lesssim$15-keV experimental resolution in order to see how important the high seniority ($\nu_n=3$) configuration is in the lowest positive- and negative-parity states in Sc^{46}.

Finally, it can be said that the usefulness of the (d,α) reaction study to Sc^{46} emphasizes the need for its application to the investigation of many other odd-odd nuclei.

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