by D. H. Wilkinson (North-Holland Publishing Company, Amsterdam, The Netherlands, 1969). Making the usual assumptions of the statistical model that the formation and decay of the compound system are independent and uncorrelated except for conservation of energy and angular momentum gives the necessary equations. The compound-nucleus-formation cross section in the incident channel $c$ is

$$\sigma_c(E_c)=\frac{\pi}{2}\lambda\!\!\!^{-}{}_c{}^2\sum_{J\pi l j}\frac{(2J+1)}{(2I+1)}T_{lj}^{J\pi}(E_c)\,. \tag{a}$$

The transmission coefficient is

$$T_\alpha^{J\pi}=1-\sum_{\alpha'}|S_{\alpha\alpha'}^{J\pi}|^2, \tag{b}$$

where $S_{\alpha\alpha'}$ is the $S$ matrix element calculated from Eqs. (15) and (16). The compound cross section to another channel $c'$ is then

$$\sigma_{cc'}(E_c)=\frac{\pi}{2}\lambda\!\!\!^{-}{}_c{}^2\sum_{J\pi\alpha}\frac{(2J+1)}{(2I+1)}T_\alpha^{J\pi}(E_c)\times\sum_{\alpha'}T_{\alpha'}^{J\pi}(E_{c'})\Big/\sum_{\alpha''c''}T_{\alpha''}^{J\pi}(E_{c''})\,, \tag{c}$$

where the summation in the denominator extends over all possible open channels, $c''$. The total $(p,n)$ cross section results from summing over all open neutron channels $c'$ in the numerator. The particular channels which were considered here are given in the text. The corresponding transmission coefficients $T_{\alpha''}$ were calculated using the same potential wells as used to derive the results shown in Figs. 2 and 3. Below $E_p = 5.6$ MeV, the total neutron cross section $\sigma_T$ of Fig. 4 was deduced using Eq. (c); above this energy $\sigma_T$ was greater than 90% of $\sigma_c$ as calculated with Eq. (a) and so, for the purposes of generating the curve of Fig. 4, the two were considered equal.

[33] G. C. Dutt and F. Gabbard, Phys. Rev. 178, 1770 (1969); C. M. Fou and R. W. Zurmuhle, *ibid.* 176, 1339 (1968); G. Bassani and J. Picard, Nucl. Phys. A131, 653 (1969). Above an excitation $E_x \sim 0.5$ MeV in $Y^{88}$ the number of levels, as well as their spins and parities, is dubious.

[34] P. Moldauer, Phys. Rev. 123, 968 (1961).

[35] A. B. Tucker, J. T. Wells, and W. E. Meyerhof, Phys. Rev. 137, 1181 (1965).

[36] See for instance: A. K. Kerman, in *Nuclear Isospin*, edited by J. D. Anderson, S. D. Bloom, J. Cerny, and W. W. True (Academic Press Inc., New York, 1969) and the references included there.

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PHYSICAL REVIEW C VOLUME 3, NUMBER 3 MARCH 1971

# ($d$, He$^3$) Reaction on Ti$^{46}$ and Ti$^{48}$†

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The $(d,\mathrm{He}^3)$ reaction on Ti$^{46}$ and Ti$^{48}$ was studied at 19.5 MeV using a magnetic spectrometer. Results were analyzed in terms of distorted-wave Born-approximation theory from which transferred $l$ values and spectroscopic factors were obtained. Transitions with $l=1$ to the 0.808-MeV state in Sc$^{47}$ and to three states in Sc$^{45}$ were observed, indicating the presence of $2p$ protons in the ground state of Ti. The single-particle strength appears concentrated in one level in Sc$^{47}$, but considerable fragmentation of the strength is seen in Sc$^{45}$. It was found that most of the $d_{3/2}$ strength is carried by the 0.763-MeV state of Sc$^{47}$, and that the spectroscopic factor for the first $\frac{3}{2}^+$ level in Sc$^{45}$, at 12 keV, is 2.8, or 70% of the sum-rule limit. Three more states with $l=2$ were found in Sc$^{45}$, one of them known to have $J^\pi=\frac{5}{2}^+$. Assuming that the other two (1.304 and 1.799 MeV) levels have $J^\pi=\frac{3}{2}^+$, the sum of the spectroscopic factors for them is 1.07, or about 25% of the sum-rule limit.

## I. INTRODUCTION

Proton pickup from Ti$^{48}$ has been studied by Yntema and Satchler,[1] Hinterberger *et al.*,[2] and Newman and Hiebert[3] using the Ti$^{48}(d,\mathrm{He}^3)$Sc$^{47}$ reaction, and by Schwartz[4] using the Ti$^{48}(t,\alpha)$Sc$^{47}$ reaction. These authors established that the ground state, the 0.765-MeV state, and the 1.297-MeV state in Sc$^{47}$ are strongly excited in proton pickup reactions by $l=3$, $l=2$, and $l=0$, respectively. No other state was reported as being excited in those studies. However, all of them used counter-telescope particle-detection systems limiting resolution. In the high-resolution work of Lewis on the Ti$^{47}(d,\mathrm{He}^3)$Sc$^{46}$ reaction[5] three $l=1$ transitions were observed and attributed to $2p$-proton pickup. It would be rather surprising if $2p$ protons are present in the ground state of Ti$^{47}$ only and not in the other Ti isotopes.

It should be noted that the $2p$-neutron admixture in the ground state of Ti isotopes observed in the $(p,d)$ reaction[6] does not necessarily lead to the presence of $2p$ protons. The converse, however, is true: If there is $2p$-proton mixture, there also must be $2p$-neutron mixture to make the wave function a good eigenfunction of isospin.

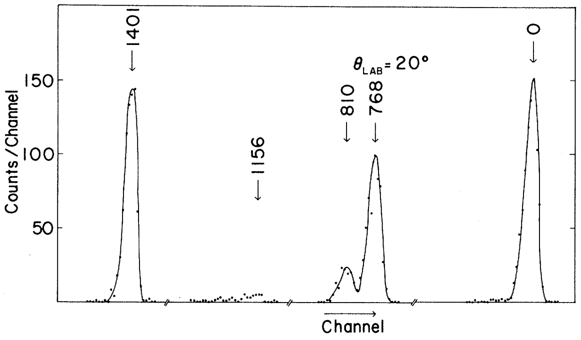

FIG. 1. $He^3$ spectrum from the $Ti^{48}(d, He^3)Sc^{47}$ reaction. Energies in keV.

During the study of the $Ti^{49}(d, He^3)Sc^{48}$ reaction[7] with a magnetic spectrometer we saw the three states in $Sc^{47}$ mentioned above due to the $Ti^{48}$ impurity in the target. In addition to these, the 0.808-MeV level in $Sc^{47}$ was identified in the spectra. In order to confirm this information, the $Ti^{48}(d, He^3)Sc^{47}$ reaction was studied with a magnetic spectrometer, and angular distributions were taken. The state in question is established[8, 9] to be $\frac{3}{2}^-$ from the study of the $\beta$ decay of $Ca^{47}$. The $Ca^{46}(He^3, d)Sc^{47}$ angular distribution to this state shows[10] a characteristic $l=1$ pattern, thus supporting the assignment. A fairly large $(He^3, d)$ spectroscopic factor $[(2J+1)c^2S=0.57]^{10}$ indicates that this state has a large portion of single-particle $p_{3/2}$ strength. Therefore if the $Ti^{48}(d, He^3)Sc^{47}$ angular distribution to the 0.808-MeV level shows a direct-reaction pattern, it would suggest a $p_{3/2}$-proton admixture in the ground state of $Ti^{48}$. Indeed the experimental angular distribution showed a forward peak, and the first maximum could be fitted by a calculated $l=1$ curve from distorted-wave Born-approximation (DWBA) theory.

At this stage the $Ti^{46}(d, He^3)Sc^{45}$ reaction was investigated. This reaction has a less negative $Q$ value than the $Ti^{48}(d, He^3)Sc^{47}$ reaction, so higher states are more easily excited. From the study of the $Ca^{44}(He^3, d)Sc^{45}$ reaction[11] three states below 2 MeV are known to be excited by $l=1$. The $Ti^{46}(d, He^3)Sc^{45}$ reaction has previously been studied only by Yntema and Satchler,[1] with a resolution of about 350 keV. Three states were excited in their work: the unresolved ground-state doublet ($l=3+l=2$) and the 0.92-MeV state ($l=0$). The spin and parity of the first excited state at 0.0124 MeV is established to be $\frac{3}{2}^+$ from later experiments.[12] The appearance of very low-lying $d_{3/2}$-hole states in Sc isotopes, and their hindered $M2$ transition rates have been explained by Lawson and Macfarlane[13] and by Bansal and French.[14] These calculations suggested that a significant fraction of the $d_{3/2}$-hole strength may be shared with higher excited states in the Sc isotopes. Such splittings of the hole strength would be easier to see in the $(d, He^3)$ reaction on $Ti^{46}$ because of its favorable $Q$ value.

## II. EXPERIMENTAL PROCEDURES

The experiment was done with the 19.5-MeV deuteron beam from the University of Minnesota J. H. Williams Laboratory tandem Van de Graaff. Self-supporting metallic targets 50–100 $\mu g/cm^2$ thick were used. Enrichment was 99% for $Ti^{48}$ and 83.8% for $Ti^{46}$. The $Ti^{46}$ target contained 5% $Ti^{47}$ and 9.8% $Ti^{48}$. The reaction products were analysed by a split-pole magnetic spectrometer.[15]. An array of three position-sensitive detectors of 700-$\mu$ effective thickness was placed in the focal plane of the spectrometer to detect and identify particles. Over-all resolution was about 20 keV for $Ti^{48}$ and 12 keV for $Ti^{46}$, the major contribution coming from target thickness.

The $Ti^{48}(d, He^3)Sc^{47}$ reaction was also studied at 19 MeV with a different target. This additional information, combined with the kinematic shift and data from the previous $Ti^{49}(d, He^3)$ experiment,[7] eliminated the possibility that the 0.81-MeV peak seen in this experiment was due to a target impurity.

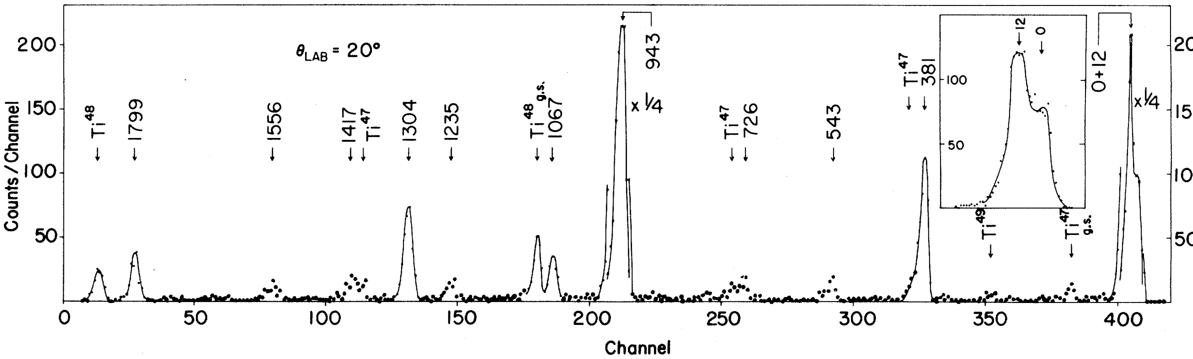

FIG. 2. $He^3$ spectrum from the $Ti^{46}(d, He^3)Sc^{45}$reaction. Energies in keV.

## III. EXPERIMENTAL RESULTS AND ANALYSIS

Typical $He^3$ spectra from the $Ti^{48}(d, He^3)$ and $Ti^{46}(d, He^3)$ reactions obtained at 20° (lab) are shown in Fig. 1 and Fig. 2, respectively. These spectra were reduced from several runs with position-sensitive detectors. The insert of Fig. 2, showing the ground-state doublet of $Sc^{45}$, is a part of the original spectrum.

In addition to levels which are known to have

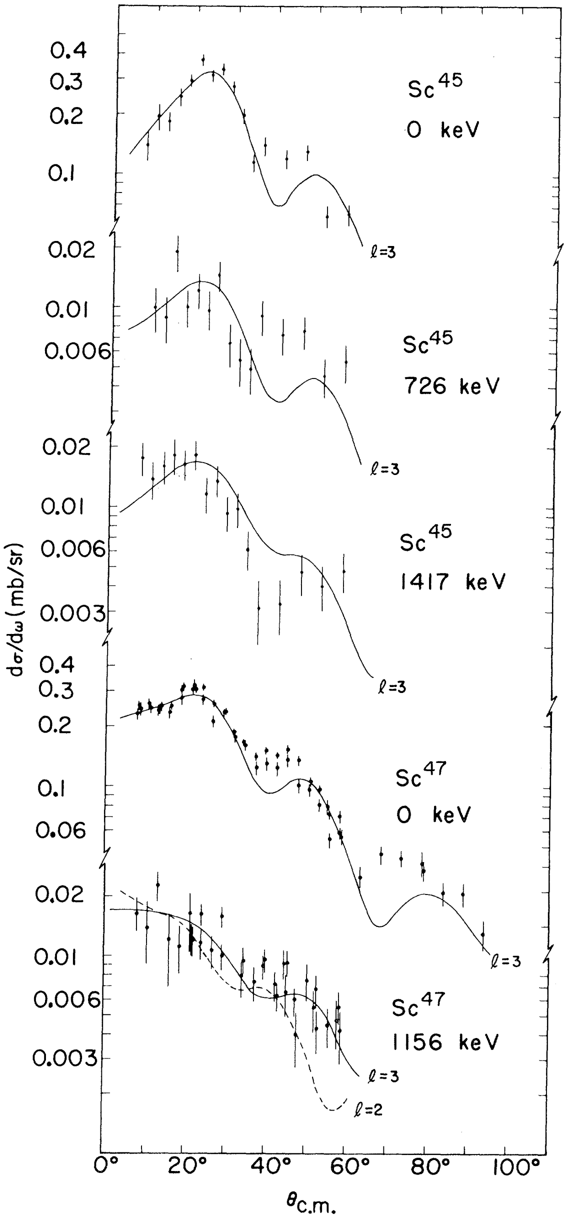

FIG. 3. Angular distributions obtained for the $Ti^{46,48}$-$(d, He^3)$ reactions, $l=3$ transitions. Solid and dashed curves show the DWBA calculations.

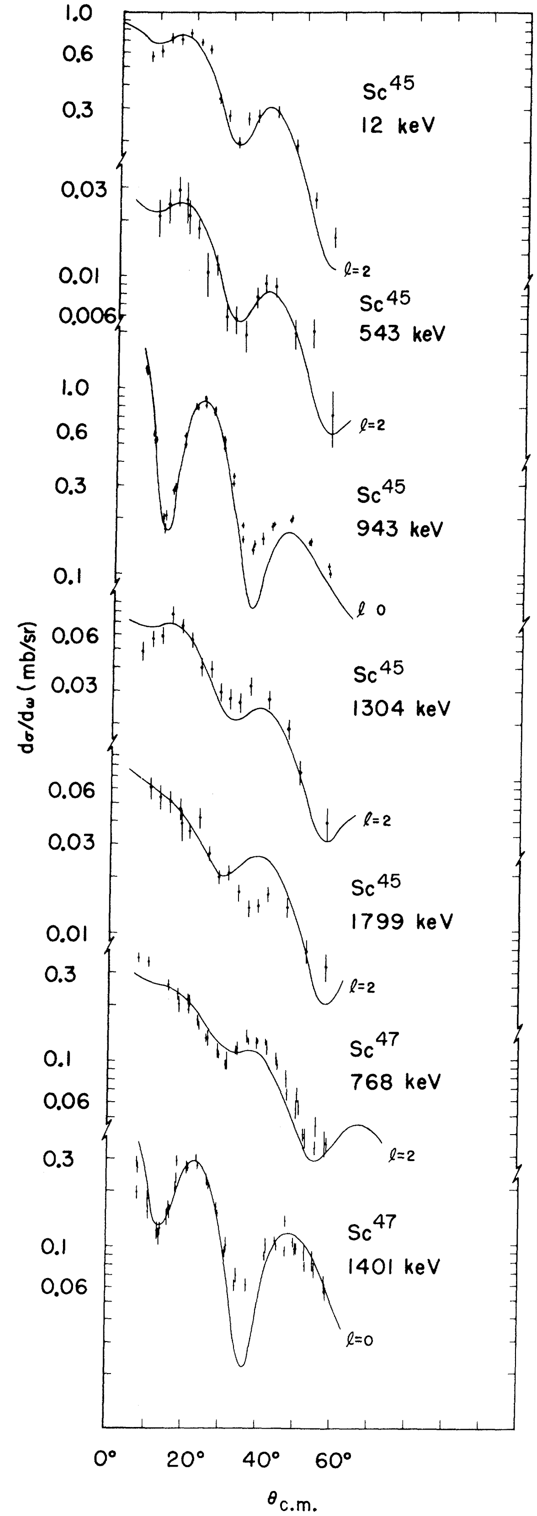

FIG. 4. Angular distributions obtained for the $Ti^{46,48}$-$(d, He^3)$ reactions, $l=0$, 2 transitions. Solid curves are DWBA calculations.

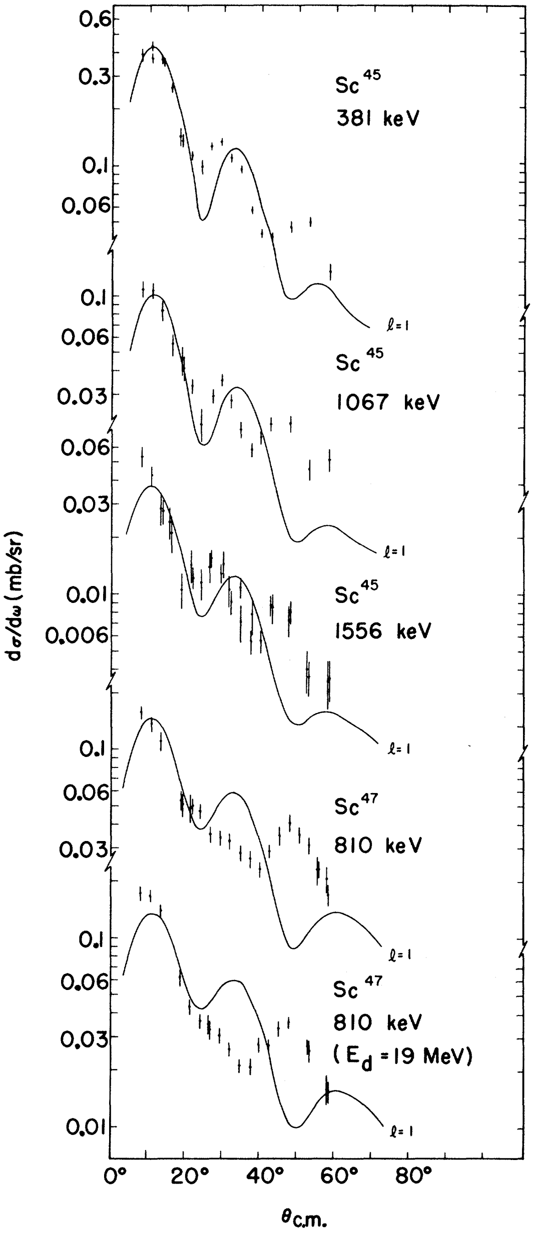

FIG. 5. Angular distributions obtained for the Ti$^{46,48}$-($d$, He$^3$) reactions, $l=1$ transitions. Solid curves are DWBA calculations.

large proton pickup strength a number of other states are also seen. Among them are the 0.81-MeV state of Sc$^{47}$ and the 0.38-, 1.07-, and 1.56-MeV states of Sc$^{45}$, all of which are excited by $l=1$ in the (He$^3$, $d$) reaction.[10,11]

Angular distributions obtained are shown in Figs. 3, 4, and 5, together with DWBA fits made using the code DWUCK.[16] The method of analysis and the optical-model parameters used (listed in Table I) are the same as those for the previous Ti$^{49}$-($d$, He$^3$)Sc$^{48}$ experiment[7]; the zero-range nonlocal approximation without a cutoff was employed and a normalization factor of 3.0 was used to extract spectroscopic factors. In other words, spectroscopic factors obtained here for the Ti$^{48}$($d$, He$^3$)Sc$^{47}$ and Ti$^{46}$($d$, He$^3$)Sc$^{45}$ reactions, and those obtained previously[7] for Ti$^{49}$($d$, He$^3$)Sc$^{48}$ are directly comparable with each other.

In Table II spectroscopic factors thus obtained are listed. For the levels shown there, all $l=1$ transitions are assumed to be due to $p_{3/2}$ pickup except for the 1.556-MeV state in Sc$^{45}$, for which the $\frac{1}{2}^-$ assignment suggested by Peterson and Perlman[17] would require a $p_{1/2}$ transition.

Among the $l=2$ levels the 763-keV state of Sc$^{47}$ and the 12-keV state in Sc$^{45}$ are well established to be $\frac{3}{2}^+$. For the 543-keV level in Sc$^{45}$, for which recent experiments[18-20] favor a $\frac{5}{2}^+$ assignment, $d_{5/2}$ pickup is assumed.

The 726- and 1417-keV states in Sc$^{45}$, although weak, can be fitted by $l=3$. Chasman, Jones, and Ristinen assigned[18] ($\frac{5}{2}^-$) to the 1410-keV level and ($\frac{5}{2}^-, \frac{7}{2}^-, \frac{9}{2}^-$) to the 725-keV state of Sc$^{45}$ from their ($p, p'\gamma$) experiment. The latter was recently assigned to be $\frac{5}{2}^-$ from Coulomb-excitation and internal-conversion measurements.[20,21] Therefore $f_{5/2}$ pickup is assumed in order to extract spectroscopic factors for these states.

A level at 1156 keV in Sc$^{47}$ is very weakly excited in the present ($d$, He$^3$) reaction. No positive assignment of an $l$ value can be made, because of poor statistics. This state was not reported in the Ca$^{46}$(He$^3$, $d$) experiment,[10] but is seen in the Ti$^{49}$-($d$, $\alpha$)Sc$^{47}$ reaction with the 3-4.3-MeV incident beam energy,[22] and also in the same reaction at 19 MeV.[23] Therefore this state is probably a hole state.

TABLE I. Optical-model parameters used for DWBA analysis.

| Particle | $V_0$ (MeV) | $r_0$ (F) | $a_0$ (F) | $W$ (MeV) | $W_D$ (MeV) | $r'$ (F) | $a'$ (F) | $V_{so}$ (MeV) | $r_C$ (F) |
|---|---|---|---|---|---|---|---|---|---|
| $d$ | 105 | 1.02 | 0.86 | ··· | 15 | 1.42 | 0.65 | 6 | 1.3 |
| He$^3$ | 173 | 1.14 | 0.723 | 18 | ··· | 1.65 | 0.8 | ··· | 1.4 |
| $p$ | adj. | 1.25 | 0.65 | ··· | ··· | ··· | ··· | $\lambda=25$ | 1.25 |

## IV. DISCUSSION

As shown in Table III the sum of the spectroscopic factors for valence orbits $(f_{7/2}, p_{3/2}, f_{5/2})$ is 2.18 for $Ti^{46}$ and 2.19 for $Ti^{48}$. The sums seem to be in reasonable agreement with the simple shell-model picture where we have two valence protons. The $p_{3/2}$ strength alone is 0.35 (0.32 if the 1.556-MeV state is $\frac{1}{2}^-$) for $Ti^{46}$ and 0.24 for $Ti^{48}$. However, one must be careful to take these numbers at their face value. It is well known[24] that spectroscopic factors for weak transitions, especially those in a pickup (stripping) reaction for higher (lower) orbits, which would be empty (filled) without configuration mixing, are unreliable because of various difficulties, one being calculation of reliable form factors.

As to the $l=1$ transitions observed here, a DWBA curve fits the first maximum, but is out of phase for the second maximum. The fit is poor for the 0.808-MeV state of $Sc^{47}$, which has the most negative $Q$ value. Several different sets of deuteron, bound-state, and $He^3$ parameters were tried, but fits were not significantly improved. Lower cutoff and finite range do not improve the fit either. Especially interesting is the insensitivity to bound-state parameters. Considerable change in form factors, especially the slope of the tail, is seen for different bound-state parameters, but resultant $(d, He^3)$ angular-distribution shapes are very much alike except for absolute values.

In short, no satisfactory fits seem to be obtained for $l=1$ within the framework of ordinary DWBA theory. There is a possibility that other reaction processes such as two step are involved in these transitions.

For both $Sc^{47}$ and $Sc^{45}$ most of the $f_{7/2}$ strength

TABLE II. Summary of present results. Spectroscopic factors from previous work are also shown.

| | Present results | | | | | $c^2S$ | |
|---|---|---|---|---|---|---|---|
| Nucleus | $E$ (keV) | $l$ | $J^\pi$ | $c^2S$ | (Ref. 1) | (Ref. 3) | (Ref. 2) |
| $Sc^{47}$ | 0 | 3 | $\frac{7}{2}^-$ | 1.95 | 2 | 1.93 | 1.8 |
| | 763 ± 5 | 2 | $\frac{3}{2}^+$ | 3.93 | 2.8 | 3.63 | 3.4 |
| | 808 ± 7 | 1 | $\frac{3}{2}^-$ | 0.24 | | | |
| | 1156 ± 10 | (2) | $\frac{5}{2}^+$ | 0.15 | | | |
| | | | $\frac{3}{2}^+$ | 0.21 | | | |
| | | (3) | $\frac{7}{2}^-$ | 0.18 | | | |
| | | | $\frac{5}{2}^-$ | 0.35 | | | |
| | 1384 ± 5 | 0 | $\frac{1}{2}^+$ | 1.90 | (2) | 2.12 | 1.4 |
| $Sc^{45}$ | 0 | 3 | $\frac{7}{2}^-$ | 1.43 | 2 | | |
| | 12 ± 3 | 2 | $\frac{3}{2}^+$ | 2.80 | 4 | | |
| | 381 ± 5 | 1 | $\frac{3}{2}^-$ | 0.23 | | | |
| | 543 ± 7 | 2 | $\frac{5}{2}^+$ | 0.08 | | | |
| | 726 ± 10 | 3 | $\frac{5}{2}^-$ | 0.15 | | | |
| | 943 ± 5 | 0 | $\frac{1}{2}^+$ | 1.55 | 2 | | |
| | 1067 ± 7 | 1 | $(\frac{3}{2}^-)$ | 0.09 | | | |
| | 1235 ± 10 | | | | | | |
| | 1304 ± 5 | 2 | $\frac{3}{2}^+$ | 0.51 | | | |
| | | | $\frac{5}{2}^+$ | 0.35 | | | |
| | 1417 ± 10 | (3) | $(\frac{5}{2}^-)$ | 0.25 | | | |
| | 1556 ± 7 | 1 | $\frac{3}{2}^-$ | 0.03 | | | |
| | | | $\frac{1}{2}^-$ | 0.04 | | | |
| | 1799 ± 7 | 2 | $\frac{3}{2}^+$ | 0.56 | | | |
| | | | $\frac{5}{2}^+$ | 0.39 | | | |

TABLE III. Sums of spectroscopic factors for proton pickup from Ti isotopes.

| | $c^2S$ | | | | | |
|---|---|---|---|---|---|---|
| Orbit | Ti$^{46}$ (present) | Ti$^{47}$ (Ref. 5) | Ti$^{48}$ (present) | Ti$^{49}$ (Ref. 7) | Ti$^{50}$ (Ref. 2) | (Ref. 3) |
| $f_{7/2}$ | 1.43 | 2.35 | 1.95 | 2.34 | 1.8 | 1.92 |
| $f_{5/2}$ | 0.40 | ... | ... | ... | ... | ... |
| $p_{3/2}$ | 0.35 [a] | 0.18 | 0.24 | ... | ... | ... |
| sum | 2.18 | 2.53 | 2.19 | 2.34 | 1.8 | 1.92 |
| $d_{3/2}$ | 3.87 [b] | 2.82 | 3.93 | 2.08 | 3.4 | 3.39 |
| $s_{1/2}$ | 1.55 | 1.57 | 1.90 | 1.68 | 1.4 | 2.14 |
| $d_{5/2}$ | 0.15 | ... | ... | ... | ... | ... |

[a] $\frac{3}{2}^-$ is assumed for the 1.06- and 1.556-MeV levels in Sc$^{45}$.

[b] $\frac{3}{2}^+$ is assumed for the 1.304- and 1.799-MeV levels in Sc$^{45}$.

is concentrated in the ground state as expected from the pure-$f_{7/2}$-model calculation.[25] However, the spectroscopic factor for the ground state of Sc$^{45}$ is only 70% of the sum-rule limit, while that for Sc$^{47}$ is close to 2.0. Furthermore, in the case of Sc$^{47}$ the 0.763- and 1.384-MeV levels carry almost all the $d_{3/2}$ and $s_{1/2}$ strength. The 12-keV state and the 0.943-MeV level of Sc$^{45}$ have only 70–80% of the total strength.

The 1.304- and 1.799-MeV states of Sc$^{45}$ have a $c^2S$ of 0.51 and 0.56, respectively, for $d_{3/2}$ pickup. The possibility that they are $\frac{5}{2}^+$ cannot be excluded, but relatively large spectroscopic factors make them more likely $\frac{3}{2}^+$: The $d_{5/2}$ single-hole state is more than 5 MeV above the $d_{3/2}$; thus low-lying $\frac{5}{2}^+$ states would have only a small fraction of the $d_{5/2}$ strength. The first known $\frac{5}{2}^+$ level in Sc$^{45}$ at 0.543 MeV has, indeed, a very small spectroscopic factor. It can thus be reasoned that a considerable amount of $d_{3/2}$ strength is shared with the two states at 1.304 and 1.799 MeV, as predicted by Lawson and Macfarlane.[13] Within the framework of their calculation there is only one such state, while here at least two levels are found which have relatively large $d_{3/2}$ spectroscopic factors. This is not unexcepted, as higher states probably have more complicated structure than that assumed in the calculation. The sum of the $d_{3/2}$ spectroscopic factors for Sc$^{45}$ is 3.87, very close to $c^2S$ for the 0.763-MeV state in Sc$^{47}$.

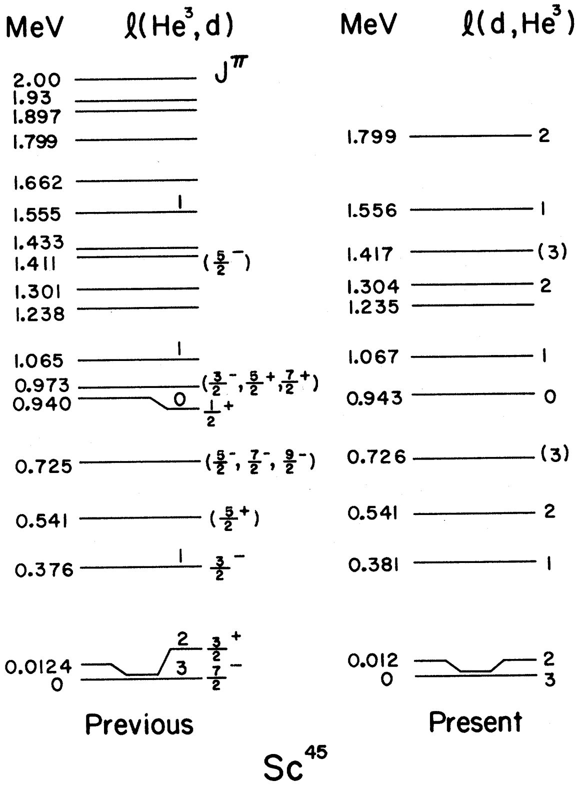

FIG. 6. Comparison of levels in Sc$^{45}$ with previous results (Refs. 8 and 18).

It is difficult to obtain accurate spectroscopic-factor sums for the ($d$, He$^3$) reaction on Ti$^{47}$ and Ti$^{49}$ because final nuclei are odd-odd and the single-particle strength is distributed among many levels. The other available proton pickup reaction which leads to an odd-$A$ Sc isotope, the Ti$^{50}$($d$, He$^3$) reaction, was not studied here; it has a very negative $Q$ value and the first $\frac{3}{2}^-$ state in Sc$^{49}$ is high (at 3.08 MeV). Thus the mass dependence of the spectroscopic factors is still ambiguous. However, there seems to be an effect of the neutron shell closure at 28 on the proton configuration.

According to Bansal and French,[26] centroids of hole states in $f_{7/2}$ nuclei can be calculated in a simple way if one assumes Ca$^{40}$ is a good core and all valence particles are in the $f_{7/2}$ orbit. Using the formulas and parameters given in their paper, one gets 0.9 and 0.08 MeV for the centroid energies of the $d_{3/2}$-hole states, and 1.3 and 1.0 MeV for those of the $s_{1/2}$-hole states, in Sc$^{47}$ and Sc$^{45}$, respectively. Calculated positions of the $d_{3/2}$- and $s_{1/2}$-hole states in Sc$^{47}$ agree well with the experimental energies of 0.763 and 1.384 MeV; qualitative agreement is seen for $Sc^{45}$. In fact, the agreement is surprisingly good despite a significant fraction of valence protons being excited into higher orbits.

The level scheme of $Sc^{45}$ deduced from the present experiment is compared with the previous one[8, 18] in Fig. 6. All recent experiments agree[19-21] that the 541-keV state is $\frac{5}{2}^+$ and the 725-keV level is $\frac{5}{2}^-$. Observed $(d, He^3)$ angular distributions are in agreement with those spin-parity assignments. Among three possibilities $(\frac{3}{2}^-, \frac{5}{2}^+, \frac{7}{2}^+)$ given by Chasman *et al.*[18] for the 973-keV state, $\frac{7}{2}^+$ is favored by the experiment of Rogers, Beghian, and Clikeman.[19] This explains why the 973-keV state was not excited at all in the $(d, He^3)$ reaction. An assignment of $(\frac{5}{2}^-)$ is given by Chasman *et al.*[18] to a state at 1409 keV, while Rogers *et al.*[19] prefer $(\frac{9}{2}^-)$ to the 1412-keV level they saw. If this state is the same as the 1417-keV level seen in this experiment, the former assignment is favored because $\frac{9}{2}^-$ would not be excited in the $(d, He^3)$ reaction.

Eastham and Phillips[20] also made a Nilsson-model calculation for the even-parity states in $Sc^{45}$ and placed a $\frac{3}{2}^+$ state about 1.3 MeV. The 1.304-MeV level is excited by $l = 2$ in the present experiment, and a relatively large spectroscopic factor favors a $\frac{3}{2}^+$ assignment. The calculation also indicates a presence of $\frac{5}{2}^+$ and $\frac{9}{2}^+$ states near 1.5 and 1.8 MeV, respectively. Since the 1.799-MeV state is strongly excited and the angular distribution is fitted by $l = 2$, it cannot be a candidate for the calculated $\frac{9}{2}^+$ level. It may correspond to the calculated $\frac{5}{2}^+$ state, but a large spectroscopic factor makes it more likely $\frac{3}{2}^+$ as discussed earlier.

Because of the large negative $Q$ value of the reaction, states in $Sc^{45}$ only up to 1.8 MeV were studied in the present experiment. It would be very interesting to look at higher states with greater incident beam energy.

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[1] J. L. Yntema and G. R. Satchler, Phys. Rev. 134, B976 (1964).

[2] F. Hinterberger, G. Mairle, U. Schmidt-Rohr, P. Turek, and G. J. Wagner, Z. Physik 202, 236 (1967).

[3] E. Newman and J. C. Hiebert, Nucl. Phys. A110, 366 (1968).

[4] J. J. Schwartz, Phys. Rev. Letters 18, 174 (1967).

[5] M. B. Lewis, Phys. Rev. C 1, 501 (1970).

[6] E. Kashy and T. W. Conlon, Phys. Rev. 135, B389 (1964).

[7] H. Ohnuma and J. L. Yntema, to be published.

[8] P. M. Endt and C. Van der Leun, Nucl. Phys. A105, 1 (1967).

[9] R. E. Wood, J. M. Palms, and P. Venugopala Rao, Nucl. Phys. A126, 300 (1969).

[10] J. J. Schwartz and W. P. Alford, Phys. Rev. 153, 1248 (1967).

[11] J. J. Schwartz and W. P. Alford, Phys. Rev. 149, 820 (1966).

[12] See Endt and Van der Leun, Ref. 8; A. E. Blaugrund, R. E. Holland, and F. J. Lynch, Phys. Rev. 159, 926 (1967).

[13] R. D. Lawson and M. H. MacFarlane, Phys. Rev. Letters 14, 152 (1965).

[14] R. K. Bansal and J. B. French, Phys. Letters 14, 230 (1965).

[15] J. E. Spencer and H. E. Enge, Nucl. Instr. Methods 49, 181 (1967); P. H. Debenham, D. Dehnhard, and R. W. Goodwin, *ibid.* 67, 288 (1969),

[16] P. D. Kunz, private communication.

[17] R. J. Peterson and D. M. Perlman, Nucl. Phys. A117, 185 (1968).

[18] C. Chasman, K. W. Jones, and R. A. Ristinen, Phys. Rev. 173, 1072 (1968).

[19] V. C. Rogers, L. E. Beghian, and F. M. Clikeman, Nucl. Phys. A137, 85 (1969).

[20] D. A. Eastham and W. R. Phillips, Nucl. Phys. A146, 112 (1970).

[21] M. D. Goldberg and B. W. Hooton, Nucl. Phys. A132, 369 (1969).

[22] J. H. Bjerregaard, P. F. Dahl, O. Hansen, and G. Sidenius, Nucl. Phys. 51, 641 (1964).

[23] R. A. Wallen, private communication.

[24] W. T. Pinkston and G. R. Satchler, Nucl. Phys. 72, 641 (1965).

[25] J. D. McCullen, B. F. Bayman, and L. Zamick, Phys. Rev. 134, 515 (1964).

[26] R. K. Bansal and J. B. French, Phys. Letters 11, 145 (1964).