PHYSICAL REVIEW C VOLUME 2, NUMBER 5 NOVEMBER 1970

Nuclear Structure of Sc^{48} from the $Ti^{49}(d, He^3)Sc^{48}$ Reaction*

H. Ohnuma
School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455

and

J. L. Yntema
Argonne National Laboratory, Argonne, Illinois 60439

(Received 3 April 1970)

The $Ti^{49}(d, He^3)Sc^{48}$ reaction was studied at 19.45 and 22.4 MeV, and spectroscopic factors were obtained. There are serious discrepancies between the present result and previous work. The present experiment supports a simple picture of the Sc^{48} nucleus.

The work of Schwartz[1] on the $Ti^{49}(t, \alpha)Sc^{48}$ reaction and its comparison with a calculation[2] has led to the postulation of a considerable amount of configuration mixing in the Sc^{48} nucleus. Several calculations[2-4] have been performed with the assumption of the pure $(\pi f_{7/2})(\nu f_{7/2}^{-1})$ configuration (or, briefly, the $f_{7/2}$ configuration). The previous $Ti^{49}(d, He^3)Sc^{48}$ experiment of Yntema and Satchler[5] did not have the energy resolution necessary for an adequate test. There are serious discrepancies between the present results and the results of Schwartz. Our data are consistent with a description in which the low-lying states of Sc^{48} correspond to a fairly pure $f_{7/2}$ configuration.

We reinvestigated the $Ti^{49}(d, He^3)Sc^{48}$ reaction at 19.45 MeV with a magnetic spectrograph and at 22.4 MeV with a counter telescope. Spectroscopic factors were obtained by comparing the experimental angular distributions with the distorted-wave (DW) theory. Important features of the Sc^{48} nucleus observed in the present experiment are as follows. (1) Four states in Sc^{48} (the ground state and the 0.133-, 0.257-, and 0.622-MeV states) are excited by $l=3$ pickup; and states at 1.091 and 1150 MeV are probably excited by an $l=3$ reaction. This result supports the assignment (made in Ref. 4) that these states are the 6^+, 5^+, 4^+, 3^+, 7^+, and 2^+, members of the $f_{7/2}$ configuration. Some calculations[1-2] predicted the 2^+ state around 600 keV, but no $l=3$ transition to such a state was found. (2) Spectroscopic factors for these states are in over-all agreement with a shell-model calculation[3] with the assumption of pure $f_{7/2}$ configuration. The anomalously large cross section to the 4^+ state seen in the (t, α) experiment[1] was not observed. (3) A transition to a state at 2.73 MeV was seen, and its angular distribution can be fitted either by $l=3$ or a mixture of $l=0$ and $l=2$. However the $l=3$ assignment suggested by Schwartz[1] is unlikely, because then the sum of the $l=3$ spectroscopic factors would considerably exceed the sum-rule limit. The 2.53-MeV level, which Ref. 4 assigned to be that 1^+ level of the $f_{7/2}$ configuration, was not seen in the present experiment. This is in accordance with the small predicted[3] spectroscopic factor. (4) Levels at 0.388 and 0.77 MeV (seen by Schwartz[1] and by Yntema and Satchler,[5] respectively, to be excited by $l=2$) are not seen. The lowest state with any hole strength is at 1.40 MeV; it was not reported by Schwartz[1] but was observed by Yntema and Satchler.[5] Therefore the centroid of the $d_{3/2}$-hole strength is much higher than had been thought. (5) In summary, the Sc^{48} nucleus looks like a good one-particle–one-hole nucleus within the framework of the present experiment.

However, in the course of the present experiment it was found that the 0.81-MeV level[6] of Sc^{47} was excited in the $Ti^{48}(d, He^3)Sc^{47}$ reaction. This indicates that there is a $p_{3/2}$ proton mixture in the ground state of Ti^{48}, even though the DW curve does not fit the experimental angular distribution very well. If about the same amount of the $p_{3/2}$ admixture is present in the ground state of Ti^{49} and its strength is spread among the 2^+, 3^+, 4^+, and 5^+ states of Sc^{48}, it would be difficult to observe in the present experiment.

The experiment at 19.45 MeV was performed with the University of Minnesota Tandem Van de Graaff and a split-pole magnetic spectrograph with position-sensitive detectors in its focal plane. Targets were metallic self-supporting foils, enriched to 77% in Ti^{49} and having thicknesses ranging from about 70 to 200 $\mu g/cm^2$. The over-all resolution width was typically 15 keV.

Experimental angular distributions are shown in Figs. 1 and 2. The curves are DW calculations. The optical-model parameters used were $V_0 = 105$ MeV, $r_0 = 1.02$ F, $a = 0.86$ F, $W' = 60$ MeV, $r' = 1.42$ F, $a' = 0.65$ F, $V_{so} = 6$ MeV, and $r_C = 1.3$ F for a deuteron; and $V_0 = 173$ MeV, $r_0 = 1.14$ F, $a = 0.723$ F, $W' = 18$ MeV, $r' = 1.65$ F, $a' = 0.8$ F, and $r_C = 1.4$ F for He^3. Bound-state parameters are $r = 1.25$ F,

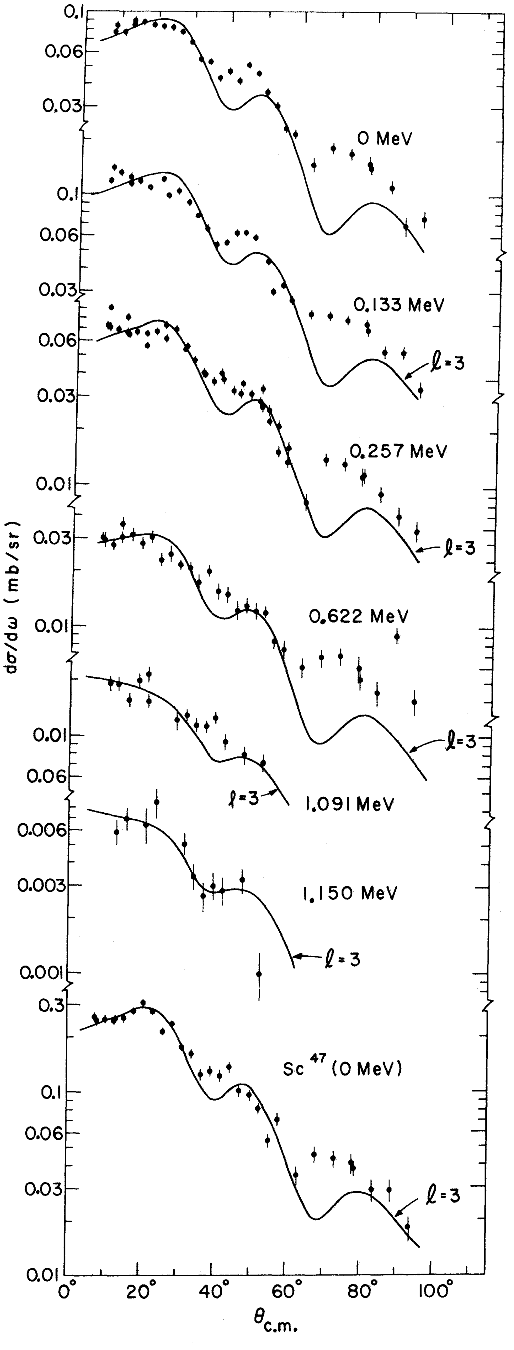

FIG. 1. Angular distributions for the $Ti^{49}(d, He^3)Sc^{48}$ reaction with $f_{7/2}$ pickup at $E_d = 19.45$ MeV. The curves are DW calculations.

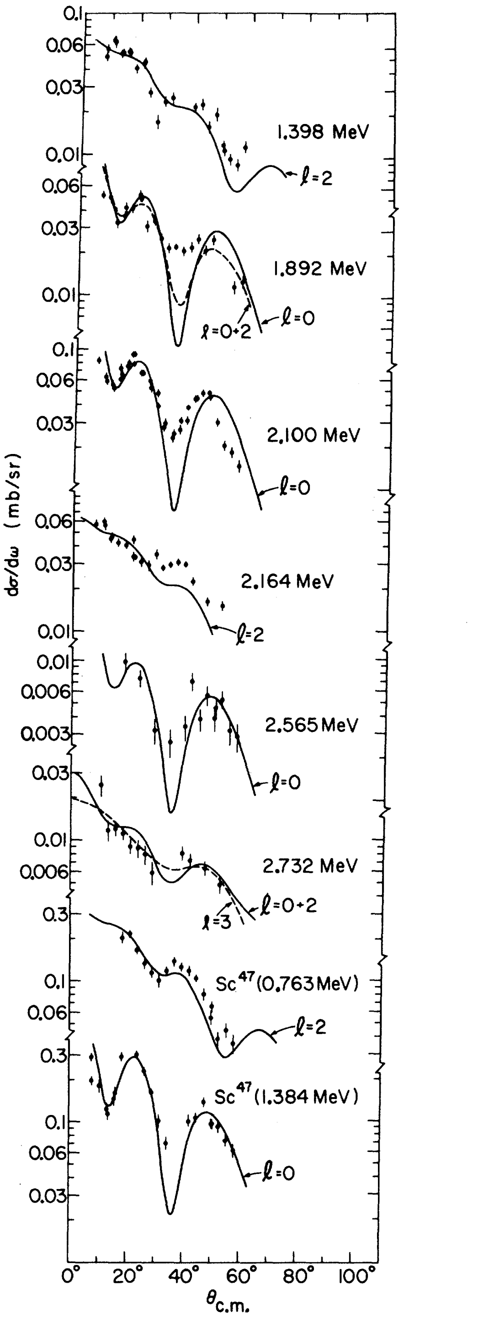

FIG. 2. Angular distributions for the $Ti^{49}(d, He^3)Sc^{48}$ reaction with $l = 0$ and $l = 2$. The curves are DW calculations.

$a = 0.65$ F, $r_C = 1.25$ F, and $\lambda = 25$. A zero-range nonlocal calculation with nonlocality parameters 0.54 for a deuteron and 0.2 for a He^3 particle was employed because it gave slightly better over-all fits. Spectroscopic factors were obtained with a normalization factor[7] of 3.

The same reaction was studied with a counter telescope and the 22.4-MeV deuteron beam from the Argonne cyclotron. In this case the over-all resolution width was about 150 keV, and the first two states in Sc^{48} and the ground state of Sc^{47} were not resolved. Therefore spectra from the $Ti^{48}(d, He^3)Sc^{47}$ reaction were measured with a 99% pure Ti^{48} target and subtracted from the spectra

TABLE I. Summary of the present results and comparison with the shell-model calculation (Ref. 3) and with previous work.

Nucleus	E_{exc} (keV)	l	J^π	Present results C^2S 19.45 MeV	22.4 MeV	C^2S (calc. from Ref. 3)	Relative C^2S Present 19.45 MeV	Calc. (Ref. 3)	Relative cross section (t,α) (Ref. 1)	
Sc^{48}	0	3	6^+	0.61	0.44	0.59	1	1	1	
	133± 5	3	5^+	0.79	0.61	0.72	1.30	1.22	1.10	
	257± 7	3	4^+	0.48	0.34	0.42	0.79	0.71	1.20	
	622± 5	3	3^+	0.21	0.19	0.15	0.34	0.25	0.28	
	1091±10	(3)	(7^+)	0.18	...	0.09	0.29	0.15	0.10	
	1150±15	(3)	(2^+)	0.07	...	0.03	0.11	0.05	...	
		(3)	(1^+)	...	...	0.01	...	0.002	0.33	
			$\sum C^2S=2.34$		1.58	2.00				
						(d, He^3), Ref. 5			(t,α), Ref. 1	
						E_{exc} (MeV)	l	C^2S	E_{exc} (keV)	l
Sc^{48}									388±20	2
						0.77	2	1.5		
	1398± 5	2		0.75		1.40	2	1.5		
	1892± 5	0		0.61					1872±20	2
		0+2		0.40+0.28						
	2100± 7	0		1.03		2.1	0	2	2100±20	0
	2164± 7	2		0.75					2140±20	2
	2395±15	...		...					2360±20	0
	2565±15	(0)		(0.1)					2530±20	0
	2732±15	0+2		0.15+0.30						
		3		0.31						
						C^2S (sum rule)	$C^2S(d, He^3)$ (Ref. 8)	(Ref. 9)		
Sc^{47}	0	3	$\frac{7}{2}^-$	1.95	1.83	2	1.93	1.8		
	763±10	2	$\frac{3}{2}^+$	3.93		4	3.63	3.4		
	1384±10	0	$\frac{1}{2}^+$	1.90		2	2.12	1.4		

with the Ti^{49} target after proper normalization. Then a peak-fitting program was applied to obtain the area under each peak. Spectroscopic factors were obtained in a similar way.

In Table I, absolute and relative spectroscopic factors are compared with the calculation by Ball[3] and with results from the (t, α) experiment.[1]

The first four states in Sc^{48} are undoubtedly excited by $l=3$ transfer. Angular distributions to the 1.091- and 1.150-MeV states are best fitted by $l=3$, although the assignments are somewhat less certain because of poor statistics and the fact that these peaks were masked at some angles by the ground-state group from the $O^{16}(d, He^3)N^{15}$ reaction. Spectroscopic factors seem somewhat overestimated at 19.45 MeV (especially for weak peaks) and underestimated at 22.4 MeV, but general agreement with the shell-model calculation is reasonably good. The (t, α) cross section to the 4^+ state, as measured by Schwartz,[1] was about 20% larger than that to the ground state, while the calculations[2,3] show that the 4^+ state should be weaker by about 30%. Our measurement agrees with the calculations and disagrees with the (t, α) experiment.

Schwartz[1] found a strong $l=3$ transition to a state at 2.70 MeV in the (t, α) reaction. This state was assigned to be the 1^+ member of the $f_{7/2}$ configuration. In the present work we saw a transition to a state at 2.732±0.015 MeV, which probably corresponds to the 2.70-MeV state observed by Schwartz. Its angular distribution can be fitted either by $l=3$ or by a mixture of $l=0$ and 2. If this transition is $l=3$, however, the spectroscopic factor is about 0.31, and hence $\sum C^2S(Sc^{48}; l=3) \approx 2.7$. We consider this to be unreasonably large compared with the value $C^2S(Sc^{47}; l=3)=1.95$ obtained in the same experiment and with the same procedure. The latter value is consistent with the values $C^2S(Sc^{47}; l=3)=1.93$ and 1.8 obtained by Newman and Hiebert[8] and by Hintenberger *et al.*,[9] respectively; $C^2S(Sc^{49}; l=3)=1.92$ and 1.8 given in Refs. 8 and 9, respectively; and with $\sum C^2S(Sc^{46};$

$l=3)=2.35$ from Lewis.[10] Therefore, if the 2.73-MeV state is excited by $l=3$, a considerable number of s-d particles must be promoted to the next shell in Ti^{49}, but not many in the other Ti isotopes. Furthermore, such an assignment makes the interpretation of the results of the $Ca^{48}(He^3, t)Sc^{48}$ experiment very difficult, as discussed in Ref. 4. It should also be noted that the (t, α) angular distribution[1] for the 2.70-MeV state could be fitted by a mixture of $l=0$ and 2.

In addition to the states of the $f_{7/2}$ configuration, levels with s-d hole components are expected at low excitation energies in Sc^{48}. Yntema and Satchler[5] saw $l=2$ transitions to states at 0.77 and 1.40 MeV and an $l=0$ transition to a state at 2.1 MeV. Schwartz[1] observed $l=2$ transitions to states at 0.388, 1.872, and 2.140 MeV, and $l=0$ transitions to states at 2.100, 2.360, and 2.530 MeV. In our experiment, no transition to a state at 0.39 or 0.77 MeV was seen. A strong $l=2$ transition was observed to a state at 1.40 MeV as it was in the work of Yntema and Satchler,[5] but it is not reported by Schwartz.[1] Schwartz assigned $l=2$ for the 1.87-MeV state in Sc^{48}. Our angular distribution to the 1.893-MeV level is fitted better by a pure $l=0$ or a mixture of $l=0$ and $l=2$. An $l=0$ transition to the 2.10-MeV state found in both previous experiments[1,5] was also seen here. The 2.165-MeV level excited by $l=2$ in our study is probably the same as the 2.140-MeV state reported by Schwartz.[1] Weak transitions to states at 2.395 and 2.565 MeV were also seen. They probably correspond to 2.36- and 2.53-MeV states reported by Schwartz,[1] who assigned both to be $l=0$. The angular distribution of the transition to the 2.565-MeV state can be fitted by $l=0$ although statistics are poor. The 2.73-MeV state was discussed above.

Bansal and French[11] calculated the centroids of the hole states in $f_{7/2}$ nuclei on the assumption that Ca^{40} is a closed-shell nucleus. Their formulas and parameters give about 0.9 and 1.3 MeV for the energies of the $d_{3/2}$ and $s_{1/2}$ hole states in Sc^{47}, respectively, about 2 MeV for the centroid of the $d_{3/2}$ hole in Sc^{48}, and slightly more than 2 MeV for the centroid of the $s_{1/2}$ hole. Calculated values for Sc^{47} are in excellent agreement with the experiment. The total strength of the $d_{3/2}$ and $s_{1/2}$ hole components in Sc^{48} was not found in the present experiment, and the spins of the hole states observed here are yet to be determined. However, it seems that the predicted values are in qualitative agreement with experiment. Especially the centroid of the $d_{3/2}$ hole states in Sc^{48} is much higher than had been thought.

---

*Work performed under the auspices of the U. S. Atomic Energy Commission.

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

[2] S. S. M. Wong, Nucl. Phys. A113, 481 (1968); J. J. Schwartz and S. S. M. Wong, Bull. Am. Phys. Soc. 12, 587 (1967).

[3] J. B. Ball, Bull. Am. Phys. Soc. 11, 349 (1966) and private communication.

[4] H. Ohnuma, J. R. Erskin, J. A. Nolen, Jr., J. P. Schiffer, and N. Williams, J. Phys. Soc. Japan Suppl. 24, 647 (1968); Phys. Rev. 1, 496 (1970).

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

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

[7] R. H. Bassel, Phys. Rev. 149, 79 (1966).

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

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

[10] M. B. Lewis, to be published.

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