Inelastic Deuteron Scattering and (d,p) Reactions from Isotopes of Titanium. IV. $Ti^{48}(d,p)Ti^{49}$†

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Levels below 6.2 MeV of excitation have been observed in the $Ti^{48}(d,p)Ti^{49}$ reaction at an incident energy of 6.0 MeV. The over-all energy resolution was 15 keV. Differential cross sections for the more intense proton groups were measured. A distorted-wave analysis yielded l_n values and spectroscopic strengths for 24 of the (d,p) transitions. A sum-rule analysis indicates that most of the $1f_{7/2}$ and $2p$ strengths were located whereas only fractions of the $1f_{5/2}$, $1g_{9/2}$, $2d_{5/2}$, and $3s_{1/2}$ strengths were found. A level scheme for Ti^{49} is proposed and the Ti^{49} level structure is compared to theoretical predictions. It is pointed out that the level structure near 2.5 MeV in Ti^{49} is not clear experimentally, though several states important for the comparison with theory occur in this region. A set of Q values is proposed for the various Ti(d,p) reactions.

I. INTRODUCTION

THE present report on the $Ti^{48}(d,p)Ti^{49}$ reaction is part of a systematic investigation of the nuclear structure of the Ti isotopes as revealed by bombardment with 6-MeV deuterons from the MIT-ONR electrostatic generator. The multigap spectrograph of Enge and Buechner[1] has been employed to obtain the spectra of scattered deuterons as well as of protons from the (d,p) reaction with an over-all resolution and precision of 15 keV or better. In earlier publications we have reported results on the $Ti^{50}(d,p)Ti^{51}$ reaction,[2] the $Ti^{47}(d,p)Ti^{48}$ reaction,[3] and the $Ti^{49}(d,p)Ti^{50}$ reaction.[4]

The excitation range from 0–6.2 MeV in Ti^{49} was investigated; the present data are compared to other experiments and a level scheme is proposed (Sec. III). The level scheme together with the available spectroscopic information is discussed in terms of current models[5–9] (Sec. IV). All these models predict that the $f_{7/2}$ strength in the $Ti^{48}(d,p)Ti^{49}$ reaction is concentrated entirely in the Ti^{49} ground state. An earlier experiment,[10] performed under conditions similar to those of the present measurement, suggested that this prediction is fulfilled. This conclusion is cast into some doubt by the identification of f strength at 2.5-MeV excitation (compare also Refs. 11–13). A summary of the ground-state Q values for (d,p) reactions on the Ti isotopes is presented in Sec. V.

II. DATA AND RESULTS

The experimental techniques have been described in detail in earlier papers of this series.[2,3] The measured angular distribution of the elastically scattered 6.00-MeV deuterons is shown in Fig. 1, together with an optical-model fit using the $B4$ parameters listed in Ref. 2. These parameters also reproduce the 6-MeV deuteron scattering from Ti^{49} and Ti^{50} with good accuracy.

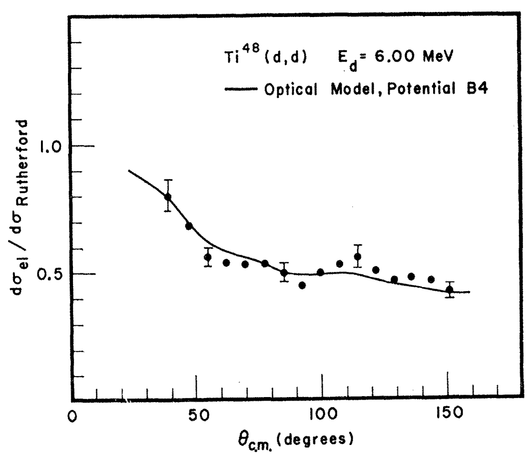

FIG. 1. Angular distribution of 6.00-MeV deuterons elastically scattered from Ti^{48}. The points are the experimental cross sections in units of the Rutherford cross section. The vertical bars indicate statistical errors only, and do not include the 24% error in absolute cross section. The solid curve is an optical-model prediction computed from a complex potential (B4 of Ref. 2) which fits the 6.00-MeV deuteron scattering from $Ti^{48,49,50}$. Further detail is given in Ref. 2.

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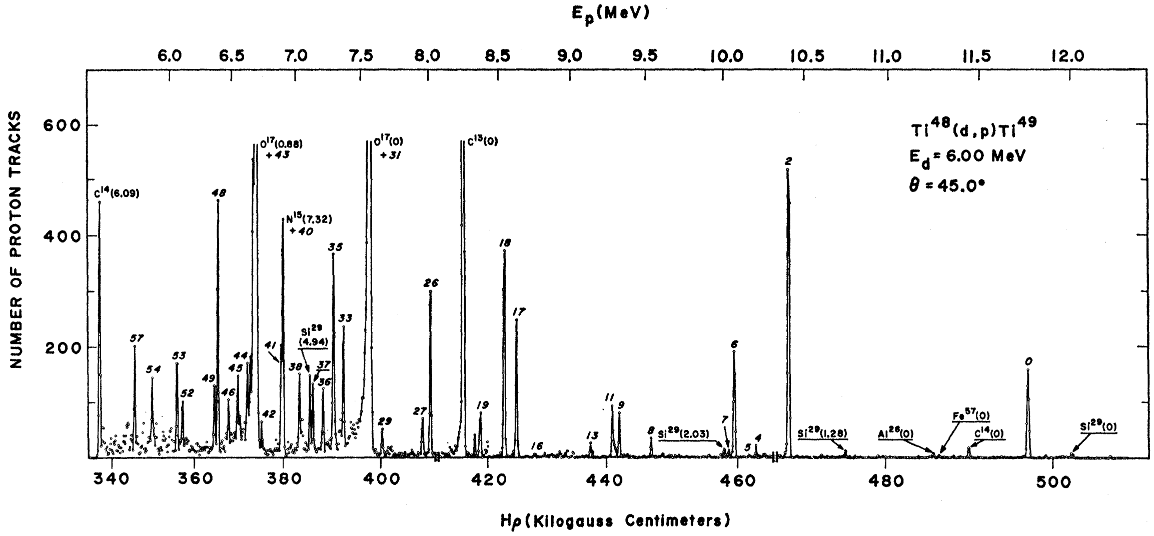

FIG. 2. Measured proton spectrum at laboratory angle 45°. The number of proton tracks in a 0.50-mm strip across the exposed zone is plotted against position along the photographic emulsion. The spectrograph calibration fixes the superimposed scale of magnetic rigidity. Proton groups identified by their kinematic shift as signifying levels in Ti^{49} are labeled with the numbers used to identify these states in Tables I and II. Prominent contaminant groups are also identified.

The spectrum of protons from an evaporated target ($\geq 99\%$ Ti^{48}), observed at 45° with 6.00-MeV deuterons incident, is shown in Fig. 2. In addition to the numbered peaks, identified from their kinematic shift as arising from Ti, proton groups from C^{12}, C^{13}, N^{14}, O^{16}, Al^{27}, Si^{28}, and Fe^{56} impurities in the target were identified. These impurity groups were used to confirm the energy scale. Because of differential hysteresis effects in the multigap magnet, the accuracy of the absolute energy scale derived from the Po^{210} α-particle calibration is limited. The difficulty was alleviated by retaining the plate-distance versus radius-of-curvature relation established with Po^{210} α particles, and using the measured positions of easily recognized impurity groups of well known Q to calculate effective magnetic fields for each gap. These effective fields (which differed at most by 0.084% from the nominal value) were in turn used to calculate the Q values for levels in Ti; differences in the Q values established the excitation energies given in Table I. The absolute value for the ground-state Q value of the $Ti^{48}(d,p)Ti^{49}$ reaction was measured in a separate

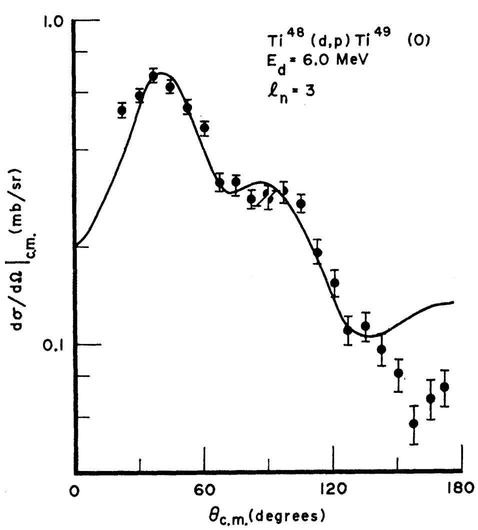

FIG. 3. Experimental proton angular distribution observed for the transition to the Ti^{49} ground state. The curve is the $l_n=3$ distribution predicted by distorted-wave Born-approximation (DWBA) calculations using potential B4 (see Ref. 2), normalized to the same area as experimentally observed. This normalization yields the strength cited in Table I.

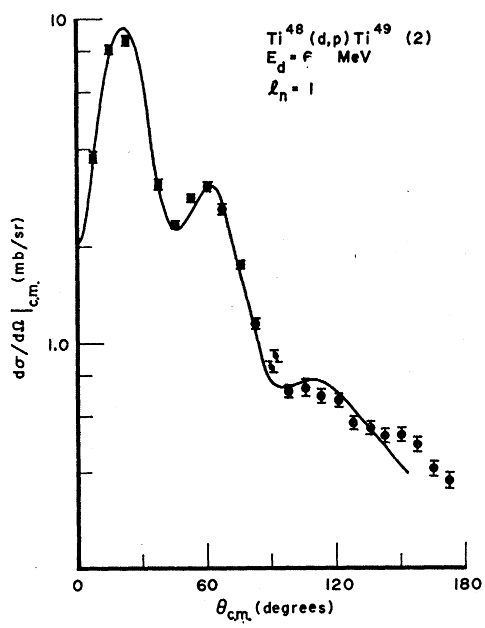

FIG. 4. Observed proton angular distribution for the transition to $Ti^{49}(2)$, together with the $l_n=1$ DWBA curve. See also caption for Fig. 3.

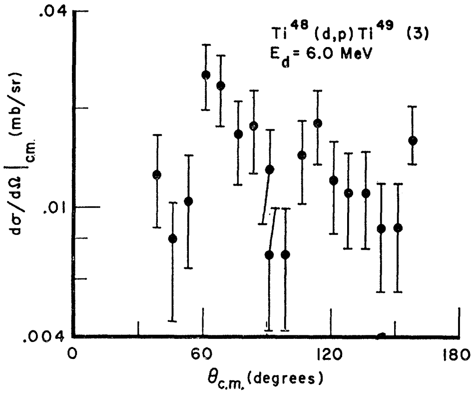

FIG. 5. Transition to Ti^{49}(3). The distribution does not show a "stripping" character.

experiment on the MIT single-gap spectrograph, as described in Sec. V.

Angular distributions for selected proton groups are shown in Figs. 3–11, together with curves from distorted-wave (DW) calculations. A complete set of angular distributions may be obtained from the authors. The orbital angular-momentum transfers (l_n values) and the spectroscopic strengths as listed in Table I were obtained by comparing experiment and calculation (see, e.g., Ref. 2). Table I also gives the maximum cross section observed for each proton group. The error in the absolute cross-section scale is $\pm 24\%$. Because of the increasing complexity of the spectrum, weak transitions to levels at excitation higher than 5 MeV may have been missed.

III. COMPARISON WITH OTHER EXPERIMENTS

The level scheme of Ti^{49} constructed from charged-particle and (n,γ) data is given in Table II. With regard

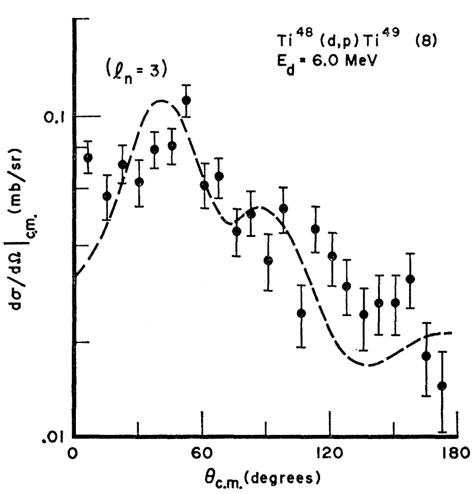

FIG. 6. Transition to Ti^{49}(8). This state is observed with an $l_n=3$ angular distribution in the $Ti^{50}(p,d)$ reaction and is considered to be a $1f_{7/2}$ hole state (Refs. 17, 18). The dashed $l_n=3$ curve is the DWBA prediction for the transition expected for a simple stripping process to a $1f$ state.

TABLE I. Summary of results of the present measurement. Numbers taken from Table II, which serve to identify Ti^{49} states, are given in the first column. The second column lists excitation energies assigned from the present multigap spectrograph data. For levels below 3.5 MeV, an error of 8 keV is assigned; above 3.5 MeV, the error is 12 keV. In columns 3 and 4 are given the values of the orbital angular momentum of the transferred neutron, and the transition strengths, both being derived from a DW analysis of the measured angular distributions. Doubtful assignments of l_n are enclosed in parentheses; "No l_n" indicates an angular distribution which cannot be fitted in a stripping theory. The lack of an entry in column 3 signifies that reliable angular distribution data were not obtained. The last column lists the maximum cross section measured; numbers in the last two columns are subject to a 24% error in the absolute cross section. The shell-model assignments used for the DW analysis were for $l_n=1$, $2p$; for $l_n=2$, $2d$; for $l_n=3$, $1f$; for $l_n=4$, $1g$; and for $l_n=0$, $2s$ in the case of state (10), $3s$ in other cases.

Level No.	E_{ex} (MeV)	l_n	$(2J_f+1)S_{lj}$	$d\sigma/d\Omega\|_{max}$ (mb/sr)
0	0	3	3.0	0.69
2	1.384	1	2.4	8.5
3	1.544	No l_n	...	0.025
4	1.587	1	0.08	0.25
5	1.625	No l_n	...	0.027
6	1.724	1	0.56	2.2
7	1.762	No l_n	...	0.12
8	2.261	No l_n	...	0.11
9	2.472	No l_n	...	0.19
10	2.503	0	0.070	0.97
11	2.517	3	0.89	0.25
13	2.665	No l_n	...	0.08
16	3.042	No l_n	...	0.020
17	3.176	1	0.37	1.7
18	3.261	(1)	(0.75)	3.3
19	3.430	(1)	(0.12)	0.39
20	3.469	1	0.05	0.26
21	3.517	No l_n	...	0.054
22	3.610	...	...	$\leq$0.05
23	3.639	...	...	$\leq$0.06
24	3.699	...	...	$\leq$0.04
25	3.749	...	...	$\leq$0.08
26	3.787	1	0.30	$\approx$1.5
27	3.844	(3)	(0.63)	0.21
28	4.075	...	...	$\leq$0.13
29	4.143	No l_n	...	0.19
30	4.195	...	...	$\leq$0.06
31	4.222	1	0.14	0.74
32	4.360	...	...	$\leq$0.12
33	4.434	1	0.15	0.97
34	4.456	No l_n	...	0.43
35	4.505	(2)	(0.49)	1.3
36	4.588	1	0.10	0.58
37	4.667	(1)	(0.12)	0.85
38	4.770	(4)	(4.0)	0.46
39	4.836	No l_n	...	0.10
40	4.897	2	0.39	1.4
41	4.911	No l_n	...	0.76
42	5.063	...	...	$\leq$0.13
43	5.120	No l_n	...	4.8
44	5.173	No l_n	...	0.29
45	5.253	(0)	(0.035)	0.88
46	5.326	No l_n	...	0.32
47	5.375	...	...	$\leq$0.12
48	5.412	(0)	(0.12)	1.8
49	5.437	1	0.06	0.41
50	5.579	...	...	$\leq$0.08
51	5.655	...	...	$\leq$0.25
52	5.693	(1)	(0.05)	0.31
		(2)	(0.07)	
53	5.737	1	0.11	$\approx$0.90
54	5.931	No l_n	...	0.47
55	5.965	...	...	$\leq$0.18
56	6.010	...	...	$\leq$0.27
57	6.078	...	...	$\leq$0.45
58	6.145	...	...	$\leq$0.18
59	6.168	...	...	$\leq$0.16

TABLE II. This table lists the authors's best estimate of the Ti^{49} level scheme to 6-MeV excitaton. Levels observed in different reactions are identified solely on the basis that the measured energies agree with the stated errors, except as noted explicitly in the text. Identification numbers are assigned in the first column. For the sake of definiteness, excitation energies measured in the present experiment are listed; for other levels the values cited in Refs. 14 and 15 are cited. Brackets are used to group unresolved levels.

Level No.		J^π	Level observed in reaction (d,p)	(n,γ)	(d,t)	(p,d)	(p,p')	(d,α)
0	0	$\frac{7}{2}^-$	a, b, c, d	e	f	g, h	a	b
1	1.309				{		a	
2	1.384	$\frac{3}{2}^-$	a, b, c, d	e			g, h		b
3	1.544		b d				a	b
4	1.587	$(\frac{3}{2}^-)$	a, b, d	e	{f}	g, h	a	b
5	1.625		a, b, d				a	b
6	1.724	$\frac{1}{2}^-$	a, b, c, d	e					b
7	1.762		a, b, c, d	e	}		a	b
8	2.261	$(\frac{7}{2}^-)$	a, b, d		{	g, h	a	b
9	2.472		b, c, d						b
10	2.503	$\frac{1}{2}^+$	{b} {c} d	e			{g, h}		{b}
11	2.517	$\frac{7}{2}^-, \frac{5}{2}^-$	d		{f}			
12	2.557		b						
13	2.665	$(\frac{3}{2}^+)$	b, d				g, h		b
14	2.720				}			b
15	2.981							b
16	3.042		d					b
17	3.176	$\frac{3}{2}^-, \frac{1}{2}^-$	b, c, d, i	e				
18	3.261	$(\frac{3}{2}^-, \frac{1}{2}^-)$	b, c, d, i	e				
19	3.430	$(\frac{3}{2}^-, \frac{1}{2}^-)$	b, d					
20	3.469	$\frac{3}{2}^-, \frac{1}{2}^-$	b, d					
21	3.517		b, d					
22	3.610		b, d					
23–59	See Table I							

[a] Reference 14. [b] Reference 15. [c] Reference 10. [d] Present work.
[e] Reference 16. [f] Reference 13. [g] Reference 17. [h] Reference 18.
[i] *Note added in proof.* L. L. Lee and J. P. Schiffer [Phys. Rev. **154**, 1097 (1967)] assign spins of $\frac{1}{2}^-$ to state (17) and $\frac{3}{2}^-$ to state (18) from the j dependence of their recent (d,p) data.

to level energies there is good over-all agreement between the present data and previous high-resolution (d,p) data[10,14,15] and (n,γ) data.[16]

Rietjens and Bilaniuk[10] have measured (d,p) angular distributions at $E_d = 7.8$ MeV for levels up to 4-MeV excitation in Ti^{49}. For $l_n=1$ levels, the relative spectroscopic strengths derived in Ref. 10 by plane-wave methods agree with the present results. The ratio of the $l_n=3$ strength of the ground state to the $l_n=1$ strength of the first excited state obtained in the present experiment is a factor of 2 larger than that obtained by Rietjens and Bilaniuk. Since the relative cross sections agree, the difference lies in the method of analysis. The 2.49-MeV level of Ref. 10, there assigned $l_n \geq 2$, probably is a superposition of levels (10) and (11).

Not listed in Table II are the two low-resolution (d,p) experiments of Yntema[11] and of Schiffer, Lee, and Zeidman,[12] in which gross structure peaks were identified with single-particle levels. A comparison of these results with the present data shows qualitative agreement in the location of the $l_n=1$ and 3 strengths, while the $l_n=0$ strength as well as the $l_n=2$ strength at 5.7 MeV reported in Ref. 15 are not observed in the present experiment. The $l_n=4$ strength lies about 1 MeV higher than previously reported.

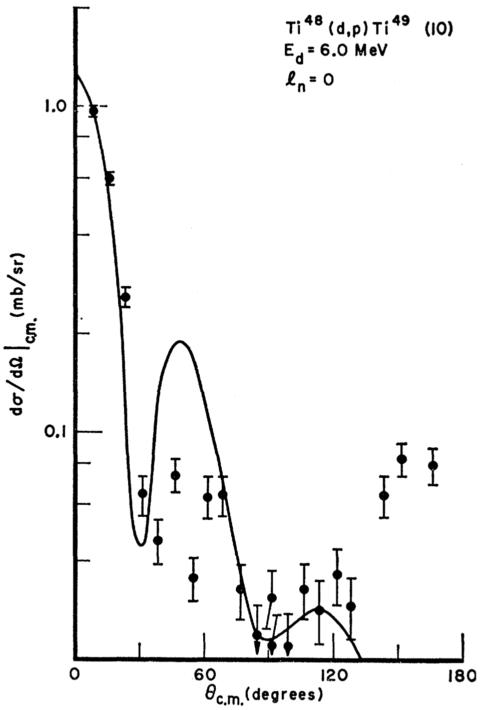

FIG. 7. Transition to Ti^{49}(10). This state is observed with an $l_n=0$ distribution in the $Ti^{50}(p,d)$ reaction, and is considered to be a $2s_{1/2}$ hole state (Refs. 17, 18). The $l_n=0$ curve is the DWBA prediction for the transition expected for a simple stripping process to a $2s_{1/2}$ state.

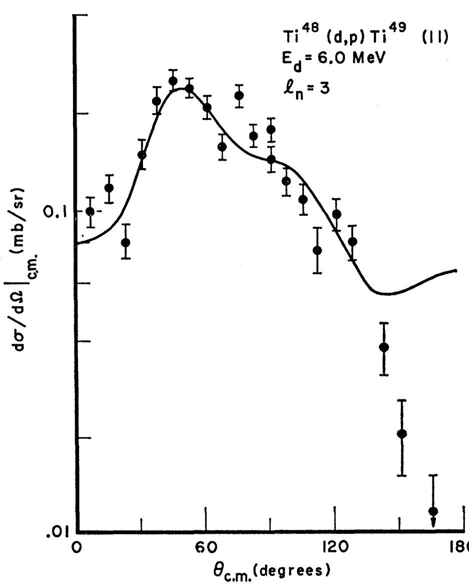

FIG. 8. Transition to Ti^{49}(11). See also caption for Fig. 3.

[14] O. Hansen, Nucl. Phys. **28**, 140 (1961).
[15] J. H. Bjerregaard, P. F. Dahl, O. Hansen, and G. Sidenius, Nucl. Phys. **51**, 641 (1964).
[16] J. W. Knowles, G. Manning, G. A. Bartholomew, and P. J. Campion, Phys. Rev. **114**, 1065 (1959).

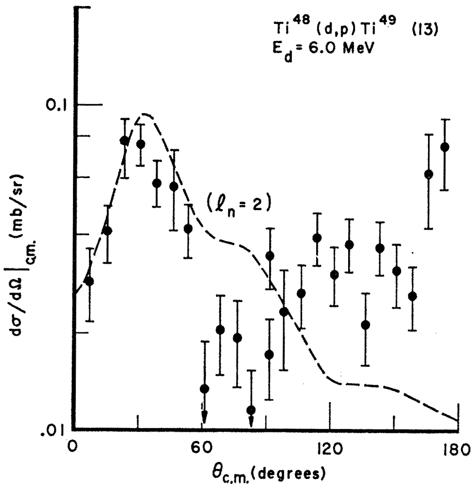

FIG. 9. Transition to Ti^{49}(13). This state is observed with an $l_n=2$ angular distribution in the $Ti^{50}(p,d)$ reaction, and is considered to be a $1d_{3/2}$ hole state (Refs. 17, 18). The dashed $l_n=2$ curve is the DWBA predictions for the transition expected for a simple stripping process to a $1d$ state.

The identification of levels from the (p,d) experiments with levels in the present experiment is somewhat tentative; the excitation energies quoted in Refs. 17 and 18 are shifted towards lower values by amounts from 20–50 keV [levels (2) and (13), respectively]. Thus we have violated the principle used in previous Ti level schemes[2–4] of identifying as the same level only such states as have the same excitation energy within the quoted limits of error. In the present instance the energy resolution obtained in the (p,d) and (d,t) experiments[13,17,18] does not allow a unique interpretation of the data near 2.5-MeV excitation. Accepting the correspondence given in Table II, levels (8), (10), and (13) have been identified in the (p,d) experiments as a $\frac{7}{2}^-$ $1f$ hole state, a $\frac{1}{2}^+$ $2s$ hole state, and a $\frac{3}{2}^+$ $1d$ hole state, respectively. The relevant (d,p) distributions are shown in Figs. 6, 7, and 9, respectively.

IV. INTERPRETATION

The spectroscopic strengths of Table I are plotted in Fig. 12 as a function of excitation energy for each value of l_n. In constructing Fig. 12 values listed as doubtful in Table I were assumed to be correct.

It is seen that the $l_n=1$ strength shows a relatively uniform distribution, so a differentiation between $p_{3/2}$ and $p_{1/2}$ transitions cannot be made on the basis of energy splitting. This trend is common for Ca and Ti isotopes with $N\leq 27$. Only three $l_n=3$ transitions were identified and it is not possible to make definite j assignments. If the two higher-lying $l_n=3$ transitions are due to $1f_{5/2}$ transfers the splitting of 2.5 MeV between the highest $1f_{7/2}$ and the lowest $1f_{5/2}$ levels would fall in between the splittings proposed in $Ti^{47}(d,p)$ ($\simeq$2 MeV) and in $Ti^{49}(d,p)$ ($\approx$3.5 MeV). In the Ca isotopes this splitting is larger than 3.5 MeV.[19]

TABLE III. The strengths of Table I summed over all states observed for each l_n [excluding the possible $2s_{1/2}$ transition to state (10)] are given in the second row. The shell-model designations expected for these values of l_n are listed in the first row. The theoretical limits are derived from the sum rules stated in Ref. 20; the values used assume a pure $(1f_{7/2})^{-2}$ configuration for $Ti^{48}(0)$.

Single-particle level	$1f_{7/2}+1f_{5/2}$	$2p_{3/2}+2p_{1/2}$	$1g_{9/2}$	$2d_{5/2}+2d_{3/2}$	$3s_{1/2}$
Experiment	4.5±1.1	5.3±1.3	4.0±1.0	0.9±0.3	0.15±0.05
Theoretical sum rule	8	6	10	10	2

In Table III the summed strengths are compared to predictions from the sum rule of Macfarlane and French,[20] assuming a $(f_{7/2})^{-2}$ neutron configuration for Ti^{48}. It is seen that the experimental result almost fulfills the p strength limit, while the other strengths are well below the limit, implying that the remaining strength lies at higher, unexplored excitation.

The theoretical calculations[5–9] for the structure of the isotopes use pure $1f_{7/2}$ configurations for the nucleons outside a doubly-magic Ca^{40} core, ignoring possible admixtures. If the assumption of a pure configuration is accepted, there is only one $\frac{7}{2}^-$ state in Ti^{49} which can be observed in the (d,p) reaction, no matter how the $f_{7/2}$ nucleons may couple to form the 0^+ ground state of Ti^{48}. This state is identified with the ground state of Ti^{49}. From Table I, the Ti^{49} ground state is observed with a strength of 3.0±0.7, exceeding the $1f_{7/2}$ sum rule limit of 2. States (11) and (27), also excited with $l_n=3$, might be identified as $\frac{5}{2}^-$ states (see above). If

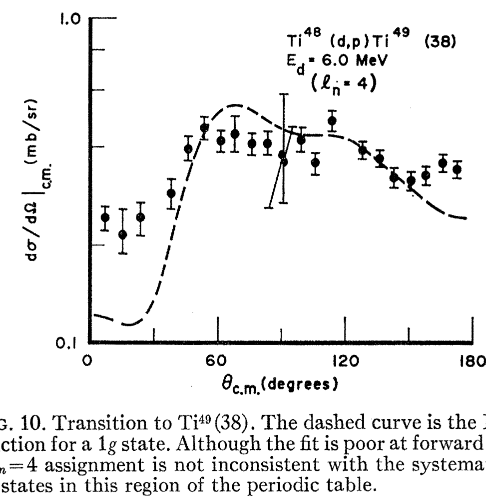

FIG. 10. Transition to Ti^{49}(38). The dashed curve is the DWBA prediction for a $1g$ state. Although the fit is poor at forward angles, the $l_n=4$ assignment is not inconsistent with the systematics for such states in this region of the periodic table.

[17] E. Kashy and T. W. Conlon, Phys. Rev. **135**, B389 (1964).
[18] R. Sherr, B. Bayman, E. Rost, M. Rickey, and C. G. Hoot, Phys. Rev. **139**, B1272 (1965).
[19] T. A. Belote, A. Sperduto, and W. W. Buechner, Phys. Rev. **139**, B80 (1965); W. E. Dorenbusch, T. A. Belote, and Ole Hansen, *ibid.* **146**, 734 (1966).
[20] M. H. Macfarlane and J. B. French, Rev. Mod. Phys. **32**, 567 (1960).

TABLE IV. Ti(d,p) ground-state Q values (keV).

Final nucleus	Ti^{47}	Ti^{48}	Ti^{49}	Ti^{50}	Ti^{51}
MIT[a]	6671 ± 6	9422 ± 6[d]	5930 ± 6	8733 ± 6	4151 ± 6
Copenhagen[b]	6672 ± 8	9414 ± 10[e]	5919 ± 8	8738 ± 10[f]	4156 ± 8
1964 mass table[c]	6651 ± 3	9404 ± 3	5922 ± 2	8720 ± 4	4154 ± 5

[a] Ti^{47}, not reported previously; $Ti^{48,50,51}$, Refs. 2–4; Ti^{49}, present data.
[b] References 14, 15. Updated to $E_\alpha=5.3042$ MeV for Po^{210} α particles used as a calibration standard.
[c] Reference 23.
[d] Using $E_{ex}=983\pm1$ keV for Ti^{48} state (1).
[e] Using $E_{ex}=2295\pm6$ keV for Ti^{48} state (2).
[f] Using $E_{ex}=1555\pm5$ keV for Ti^{50} state (1).

this identification were true, states (11) and (27) should be weakly excited in a neutron pickup reaction from ^{50}Ti, since $1f_{5/2}$ ground state admixtures probably are small.[3,21] As mentioned earlier, the experimental situation on this point is not clear.

The nature of the states near 2.5 MeV are of importance for understanding the structure of the Ti nuclei. McCullen *et al.*[6] predict three excited $\frac{7}{2}^-$ states that may all be reached by neutron pickup but not by neutron capture. The $l_n=3$ pickup strength identified in Ref. 17 near 2.3 MeV has been interpreted as leading to such a state.[6] If the (p,d) transition in fact excites state (8) at 2.26 MeV, the present results seem to confirm the small (d,p) strength predicted (see Fig. 6 and Table I). Another problem is the identification of the $l_n=2$ pickup strength; if this strength corresponds to state (13), the nonstripping character of the (d,p) transition to this level would indicate that the $1d_{3/2}$ shell is nearly filled in the Ti^{48}(g.s.) (see also the discussions in Refs. 19 and 21). A weak $l_n=0$ (d,p) transition is observed to state (10), which state is probably also excited by a strong $l_n=0$ pickup transition[17]; hence a $2s_{1/2}$ bound-state wave function rather than $3s_{1/2}$ was used for evaluating the (d,p) strength. A similar situation seems to exist[17,21] in Ti^{47}.

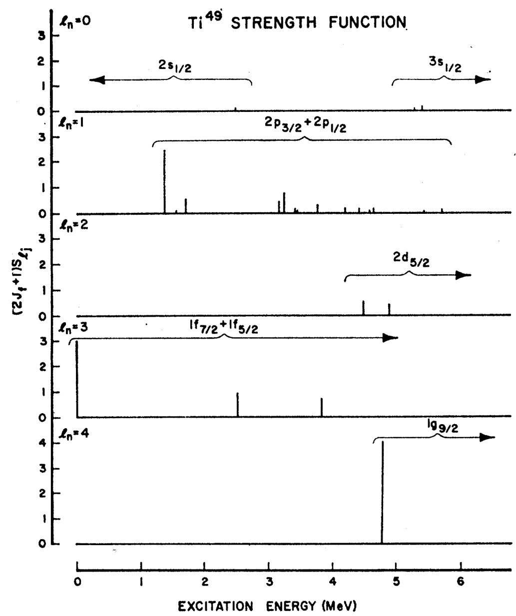

FIG. 12. The strengths $(2J_f+1)S_{lj}$ listed in Table I are plotted as a function of excitation energy for the observed values of orbital angular momentum of the transferred neutron, l_n. Assignments listed as doubtful in Table I are included here. Configuration assignments consistent with the simple shell model are indicated.

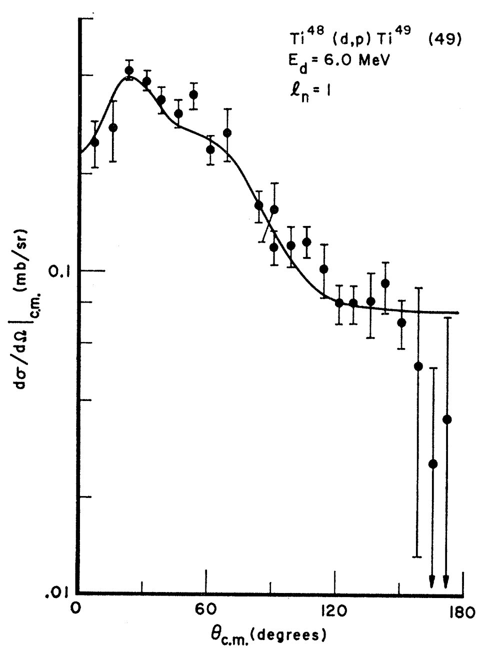

FIG. 11. Transition to Ti^{49}(49), together with an $l_n=1$ DWBA prediction. The good fit is characteristic of the $l_n=1$ transitions observed in this experiment over a wide range of proton energies (see also Fig. 4).

V. Ti Q VALUES

In Table IV the ground-state Q values for Ti(d,p) reactions obtained in the present series of measurements are given.[22] Also shown are the Copenhagen[14,15] Q values, updated to the calibration energy of 5.3042 ±0.016 MeV for Po^{210} α particles used in the present work, and the Q values computed from the 1964 mass tables.[23]

The present data are derived from several exposures using a Ti target of natural isotopic abundance and the MIT single-gap spectrograph. Hence all (d,p) groups were obtained simultaneously. The interpretation of the proton spectrum was carefully checked against spectra obtained from the isotope-separated targets.

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[22] Preliminary Ti(d,p) Q values were reported by A. Sperduto and W. W. Buechner, in *Proceedings of the International Conference on Nuclear Masses* (Springer-Verlag, Vienna, 1964), p. 289. The present values supersede the preliminary reported values.

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The general agreement between the two sets of (d,p) measurements is satisfactory, although in the $Ti^{48}(d,p)$-Ti^{49} case the agreement is just within the limits of error.

The agreement between the reaction data and the data computed from the mass table[23] is unsatisfactory for the Ti^{47}, Ti^{48}, and Ti^{50} cases, whereas it is acceptable in the case of Ti^{49}. The good agreement in the Ti^{51} case is not significant since the mass value for this nucleus was derived mainly from the MIT Q value. The reason for the above discrepancies is not understood but it is hoped that further reaction Q value measurements in progress applying more refined techniques will clarify the situation.

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Coulomb Excitation of Low-Lying Excited States in Sc^{45}†

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Properties of the first excited state of Sc^{45} at 12.4 keV and the second excited state at 376 keV have been measured. A limit on the admixture of $E3$ radiation in the predominantly $M2$ decay of the first excited state has been set by looking for $E3$ Coulomb excitation of this state with Cl^{35} ions. Our result is that $B(E3,\frac{7}{2}^- \rightarrow \frac{3}{2}^+) \leqslant 105\ e^2\text{fm}^6 = 2.7$ single-particle units. The mean lifetime has been remeasured as $\tau = 0.470 \pm 0.006$ sec. The K-conversion coefficient has been measured as 580 ± 120. The energy of the second excited state was determined to be 375.5 ± 1.0 keV. It was found to decay primarily to the first excited state with a branching ratio of 10.8 ± 0.5. The reduced matrix element for Coulomb excitation of the second excited state was measured to be $B(E2, \frac{7}{2}^- \rightarrow \frac{3}{2}^-) = 60.5 \pm 10\ e^2F^4$.

I. INTRODUCTION

SINCE the discovery by Yntema and Satchler[1] that the scandium isotopes have $\frac{3}{2}^+$ states very near the ground state, a number of investigators have reported on the properties of these states.[2–5] Bansal and French[6] calculated the excitation energies of these states on the assumption that a $d_{3/2}$ hole is coupled to the ground state of the neighboring even-A nucleus. From their description, it follows that the transition from the hole states to the ground state should have predominantly an $M2$ character. The experimental lifetimes show a very retarded $M2$ transition rate. Lawson and Macfarlane[7] and Bansal and French[8] were able to explain this retardation as a result of a mutual cancellation of terms in the transition moments, an effect stemming from coupling the $d_{3/2}$ hole to the ground state and first excited state of Ti^{46}. From these wave functions Lawson[9] also calculated the $E3$ transition rate as 0.7 Moszkowski single-particle units.

On the other hand, there existed no direct experimental evidence for assigning these transitions a pure $M2$ character, and the presence of a sizeable $E3$ component could not be excluded. de-Shalit[10] pointed out that the low-lying positive-parity states in the Sc isotopes could be described in terms of a dominant configuration consisting of an $f_{7/2}$ particle coupled to a 3^- even-A core. Such a description would result in γ-ray transitions having predominantly an $E3$ character. These transition probabilities would have approximately the same values as the $3^- \rightarrow 0^+$ transitions in neighboring even-A nuclei. In these neighbors, the $E3$ transitions are enhanced to ~ 20 times the single-particle estimates.

In Sc^{45} the low excitation energy of the $\frac{3}{2}^+$ state means that the single-particle $E3$ transition probability is only 10^{-8} of the corresponding single-particle $M2$ transition rate. In order for the observed transition

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