proton radii equal – is shown in Fig. 3; it is as much as 8.8% for Pb.

IV. CONCLUSIONS AND COMMENTS

The ratio of π^+/π^- absorption cross sections is sensitive to details of the neutron density, assuming the proton density is known already, e.g., from electron scattering. It provides a useful constraint on the neutron distribution – one which contains information about the nuclear surface, although it does not fix uniquely a particular moment or parameter. An accuracy of a few tenths of a percent in the ratio is required for interesting results. The validity of the optical model used can be verified by studying the energy dependence of the cross sections[1] and of the ratios,[2] and is itself an interesting question worth further study. Note that the ratios are quite insensitive to the optical parameters used.[1]

Differential elastic $\pi^{\pm}$ scattering data will also be quite sensitive to details of the nucleon densities, particularly at large momentum transfers.[1] This will be explored in a later paper.

ACKNOWLEDGMENT

One of us (MMS) would like to thank Los Alamos Scientific Laboratory for its hospitality. J. Silver and A. Lopez assisted with the computations.

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*Research supported in part by the National Science Foundation. Part of this work was done while the author was a Visiting Staff Member at Los Alamos Scientific Laboratory.

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

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PHYSICAL REVIEW C VOLUME 4, NUMBER 5 NOVEMBER 1971

High-Spin Proton States Observed in the Reactions $^{90}Zr(\alpha, t)^{91}Nb$ and $^{92}Mo(\alpha, t)^{93}Tc$ at 50 MeV*

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(Received 16 April 1971)

The reactions $^{90}Zr(\alpha, t)^{91}Nb$ and $^{92}Mo(\alpha, t)^{93}Tc$ have been investigated with a 50-MeV α-particle beam from the Berkeley 88-in. cyclotron. Comparisons are made with the results of ($^3He, d$) experiments on the same targets in order to locate high-spin ($l > 2$) levels in ^{91}Nb and ^{93}Tc. The ^{91}Nb(4.18 MeV) and ^{93}Tc(3.91 MeV) levels are probable l=4 or 5 levels, in contrast to the ($^3He, d$) results. A difference in Q values for the reactions $^{90}Zr(\alpha, t)^{91}Nb$ and $^{91}Zr(\alpha, t)$-^{92}Nb of 680± 25 keV yields a Q value for the reaction $^{90}Zr(\alpha, t)^{91}Nb$ of −14.643± 0.027 MeV, which is not consistent with the presently accepted mass excess of −86.750± 0.06 MeV for ^{91}Nb.

I. INTRODUCTION

In recent years there have been many studies[1-6] of proton configurations in the $N = 50$ nuclei ^{91}Nb and ^{93}Tc. The locations of these proton states are of interest for comparison with shell-model calculations[7,8] and the centroid positions are useful in predicting energies of two-particle proton-neutron states in nearby odd-odd nuclei. The states expected in proton transfer to ^{90}Zr and ^{92}Mo are (suppressing radial quantum numbers) $g_{9/2}$, $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $s_{1/2}$, and possibly $h_{11/2}$. The (^{3}He, d) reaction, however, preferentially populates the lower-angular-momentum states (i.e., $l=0$, 2). Thus, it is not a very efficient method for locating high-spin states such as $g_{9/2}$, $g_{7/2}$, or $h_{11/2}$, particularly if these states are fragmented into many levels. In the ^{92}Mo(^{3}He, d)^{93}Tc reaction, which has been studied in detail at 18 and 35 MeV,[1,5] *no* $l=4$ levels have been reported except for the ground state, although several have been seen in the ^{90}Zr(^{3}He, d)^{91}Nb experiments.[1,2,4,6] The large momentum transfer in the (α, t) reaction, compared with that in the (^{3}He, d) reaction, favors the excitation of high-angular-momentum proton states. [$\vec{Q}\times\vec{R} \approx 6$ for the (α, t) reaction at 50 MeV on ^{90}Zr.] A comparison of the relative strengths of various states observed in both the (^{3}He, d) and (α, t) reactions should, therefore, give some information on the location of high-orbital-angular-momentum ($l=4$ or 5) levels in ^{91}Nb and ^{93}Tc.

II. EXPERIMENTAL

The experiment was performed with a 50-MeV α-particle beam from the Berkeley 88-in. cyclotron at a beam resolution, $\Delta E/E$, of 0.04%. The targets were self-supporting metal foils of ^{90}Zr (enriched to 97.8%) and ^{92}Mo (enriched to 98.3%), whose nominal thicknesses were 0.20 and 0.30 mg/cm^2, respectively. Due to large uncertainties in the target thicknesses, absolute cross sections for both reactions are accurate only to about ±50%. *Relative* cross sections for each target, however, should be correct to ±15%. Tritons were detected with two counter telescopes, each consisting of a 0.25-mm phosphorus-diffused Si ΔE and 5-mm Si(Li) E detector, and identified with a Goulding-Landis particle identifier.[9]

III. RESULTS AND DISCUSSION

A. ^{90}Zr(α, t)^{91}Nb

Since the previously reported level energies from ^{90}Zr(^{3}He, d)^{91}Nb experiments[1,2,4,6] indicate rather substantial discrepancies, we remeasured them. [The energies reported in Refs. 1 and 6 are systematically higher than those found in Ref. 2, and the differences appear to increase with excitation energy. For example, the strongest peak in ^{90}Zr(^{3}He, d)^{91}Nb is assigned excitation energies of 3.360 ± 0.015,[2] 3.395 ± 0.015,[1] and 3.410 ± 0.010[6] MeV.] Our spectra were calibrated with the ^{17}F(g.s.) impurity peak and ^{91}Nb(g.s.) peak as a function of angle.[10] The Q value for the ^{16}O(α, t)^{17}F reaction, −19.2136 MeV, was taken from published tables.[11] However, recent results of various reactions leading to ^{91}Nb give conflicting results for the mass excess of that nucleus.

A ^{90}Zr(^{3}He, d)^{91}Nb experiment[6] gives a Q value of -0.227 ± 0.020 MeV, which is essentially identical to the published[11] Q value obtained from the Mass Table of Mattauch, Thiele, and Wapstra.[12] But the ^{91}Zr(p, n)^{91}Nb reaction[13] gives $Q=-2.045\pm0.006$ MeV, which changes the mass excess of ^{91}Nb used in Ref. 11 by +120 keV. Our mass of ^{91}Nb comes from the relative Q values of the ^{90}Zr(α, t)-^{91}Nb and ^{91}Zr(α, t)^{92}Nb reactions, which were observed[14] simultaneously with a ^{91}Zr target containing about 5% ^{90}Zr impurity. The energy calibration of the ^{91}Zr(α, t) data [using the ^{17}F(g.s.) and ^{92}Nb(g.s.) as a function of angle, with Q values as given in Ref. 11] gives a difference in Q values of 680 ± 25 keV between the ^{90}Zr(α, t)^{91}Nb and ^{91}Zr(α, t)^{92}Nb reactions. Ball and Cates[15] found a difference in (^{3}He, d) Q values for the two isotopes of 677 ± 7 keV, which is essentially identical to our (α, t) results[14] and has a much lower uncertainty. The difference in Q values obtained by Ball and Cates[15] corresponds to a ^{90}Zr(^{3}He, d)^{91}Nb Q value

TABLE I. Summary of Q values for reactions relating to ^{91}Nb.

Reaction	Measured Q value (MeV)	Published Q value[a] (MeV)	^{91}Nb mass excess[b] (MeV)
^{91}Zr(^{3}He, d)^{92}Nb	···	0.358 ± 0.011	···
^{91}Zr(α, t)^{92}Nb	···	-13.963 ± 0.011	···
^{91}Zr(p, n)^{91}Nb[c]	-2.045 ± 0.006	-1.925 ± 0.060	-86.630 ± 0.008
^{90}Zr(^{3}He, d)^{91}Nb[d]	-0.227 ± 0.020	-0.225 ± 0.060	-86.748 ± 0.020
"	-0.319 ± 0.013[e]	"	-86.656 ± 0.014
^{90}Zr(α, t)^{91}Nb	-14.643 ± 0.027[f]	-14.545 ± 0.060	-86.652 ± 0.027

[a] Taken from Ref. 11, which uses a mass excess for ^{91}Nb (from Ref. 12) of -86.750 ± 0.060 MeV.
[b] Calculated from the difference between the measured and published Q values.
[c] Reference 13.
[d] Reference 6.
[e] Relative to ^{91}Zr(^{3}He, d)^{92}Nb Q value listed above. Q-value difference from Ref. 15 (see text).
[f] Relative to ^{91}Zr(α, t)^{92}Nb Q value listed above. Q-value difference from Ref. 14 (see text).

TABLE II. Levels observed in the reaction $^{90}Zr(\alpha, t)^{91}Nb$ at 50 MeV.

	(α, t)		$(^3He, d)$			^{91}Mo(g.s.) decay
No.	Levels observed [a] (MeV)	Intensity [b] (mb)	Levels observed [c,d] (MeV)	l_p [d]	C^2S [d]	Levels observed [e] (MeV)
1	0.0	3.441	0.0	4	0.918	...
2	(0.103) [f]	0.144	0.103	1	0.430	
3	1.29	0.038 [g]	1.31	1	0.048 [h]	
						1.581
4	1.60	0.073	1.60	1	0.078 [h]	1.637
						1.791
5	1.82	0.069 [g]	1.84	3	0.058 [h]	
6	1.95 ± 0.04	Weak	1.96	2 [h]	0.014 [h]	
7	2.30	0.043 [i]	2.34	1	0.017 [h]	
8	2.39 ± 0.03	Weak				(2.391) [j]
9	2.53	0.032 [i]				2.531
10	2.61	0.023 [k]	2.62 [l]		Weak [l]	2.631
						2.792
11	2.77	0.012 [k]				
12	2.90	0.074	2.92 [l]		Weak [l]	
13	3.01	0.036 [m]				3.028
			3.07 }	2	0.035	
14	3.12 ± 0.04	Weak	3.11 }			3.149
						3.187
15	3.37	0.218	3.36	2	0.388	
16	3.65 ± 0.04	0.027 [k]	3.66	2 [h]	0.023 [h]	
						3.837
						3.886
			3.92 [n]		Weak [n]	3.916
			3.95 }			
			3.99 }			
			4.11	0	0.055	
17	4.18	0.107	4.18	(2)	0.020	4.179
			4.23	(2)	0.008	
			4.30	2	0.023	
			4.39	0	0.160	
			4.49	2	0.043	
			4.61	2	0.013	
			4.70	2	0.033	
18	4.77 ± 0.03	0.232 [g]	4.77 }	4	0.343	
			4.80 }			
			4.85			
19	4.89 ± 0.03	0.096 [g]	4.90			
			4.95 }	(0)	0.055	
			4.99 }			
20	5.02 ± 0.03	Weak	5.04	0	0.040	
21	5.14 ± 0.03	0.067 [i]	5.17	(0)	0.080	
			5.24	2	0.133	
22	5.34 ± 0.03	Weak	5.33	0	0.090	
			5.44	2	0.165	
			5.57	(0)	0.035	
			5.64	0	0.060	
			5.74	0	0.020	
			5.80	0	0.120	
			5.86	0	0.045	

TABLE II *(Continued)*

No.	(α, t) Levels observed[a] (MeV)	Intensity[b] (mb)	(^{3}He, d) Levels observed[c, d] (MeV)	l_p[d]	C^2S[d]	^{91}Mo(g.s.) decay Levels observed[e] (MeV)
23	5.95 ± 0.05	(0.1)[o]	6.01	4	0.500	
24	6.09 ± 0.05	Weak	6.09	2	0.075	
			6.17	2	0.103	
			6.215[n]	(4)[n]	Weak[n]	

[a] Excitation energy ±20 keV except as noted. The Q value for the reaction was assumed to be −14.643 MeV (see text).
[b] Integrated from $\theta_{c.m.} = 12.5$ to 57° except as noted.
[c] Excitation energy ±15 keV.
[d] Taken from Ref. 2 except as noted. All $l = 2$ levels up to 5.44 MeV are assumed $d_{5/2}$. All $l = 4$ levels except the ground state are assumed $g_{7/2}$.
[e] Taken from Ref. 17. Only those levels believed to be populated in the g.s. ($\frac{9}{2}^+$) decay are included. All energies ±1 keV or less. The upper limit for the decay is about 4.4 MeV.
[f] Not resolved.
[g] Integrated from $\theta_{c.m.} = 12.5$ to 52°.
[h] Taken from Ref. 4. All $l = 1$ levels except 0.103 MeV are assumed $p_{3/2}$. The 1.85-MeV level is assumed $f_{5/2}$.
[i] Integrated from $\theta_{c.m.} = 12.5$ to 36.5°.
[j] The existence of this level was uncertain.
[k] Integrated from $\theta_{c.m.} = 12.5$ to 42°.
[l] Taken from Ref. 1.
[m] Integrated from $\theta_{c.m.} = 12.5$ to 42°.
[n] Taken from Ref. 6.
[o] Observed at only three angles. The average differential-cross-section ratio to the 4.18-MeV level (~0.9) was used in obtaining the intensity.

of −0.319 MeV [using the published ^{91}Zr(^{3}He, d) Q value],[11] which is considerably different from the value of -0.227 ± 0.020 MeV reported in Ref. 6. A summary of the relevant Q values is given in Table I.

The change in the ^{91}Nb mass excess required by Ball and Cates[15] and our own data[14] is about +95 keV, which is slightly less than the value of +120 keV indicated by the ^{91}Zr(p, n)^{91}Nb data.[13] Perhaps the discrepancy is due to an error in the ^{91}Zr-(^{3}He, d) and ^{91}Zr(α, t) Q values,[11] since the results[14, 15] from the ^{91}Zr target are only relative to these numbers. However, the (α, t) calibration[14] is also consistent with the position of the ^{92}Zr-(α, t)^{93}Nb(g.s.) peak which would mean that this Q value[11] must *also* be in error in order to agree with the results of Ref. 13. Based on these results, we feel that the ^{90}Zr(^{3}He, d)^{91}Nb Q value determined in Ref. 6 is incorrect. The ^{90}Zr(α, t)^{91}Nb Q value used in our analysis is −14.643 MeV. This corresponds to the relative difference in (α, t) Q values of 680 keV discussed above, and is slightly less negative than the value of −14.665 MeV which would be inferred from the ^{91}Zr(p, n)^{91}Nb results.[13]

The excitation energies of ^{91}Nb states observed in this work are given in Table II. The results agree, in general, with those of Vourvopoulos *et al.*[2] and indicate that the excitation energies reported by Picard and Bassani[1] and Knöpfle *et al.*[6] are somewhat too high. Of course, our method of calibration gives excitation energies that depend on the choice of Q value for the ^{90}Zr(α, t) reaction. If the *published* ^{90}Zr(α, t) Q value[11] is used, the excitation energies correspond rather well to those of Ref. 6. The errors quoted in Table II reflect an uncertainty of ±27 keV in the Q value used in our analysis, but must be considered in the context of any redetermination of this value.

A triton spectrum of the reaction ^{90}Zr(α, t)^{91}Nb at $\theta_l = 30°$ is shown in Fig. 1. The resolution is 50 keV, full width at half maximum (FWHM). The $g_{9/2}$ ground state is a factor of 15 more intense than any other single level in the spectrum. In the ^{90}Zr(^{3}He, d)^{91}Nb data at 30.9 MeV[4] the ground state has only about $\frac{1}{3}$ the intensity of the 3.36-MeV $l = 2$ level. Based on the strength of the ground state ($g_{9/2}$), the spectroscopic factors from (^{3}He, d)[2, 6] indicate that $\sigma_{9/2^+}/\sigma_{7/2^+} \approx 5$ for the (α, t) reaction.

Figures 2 and 3 show angular distributions of tritons leading to some of the stronger final states. The angular distributions of all strong triton groups show very little structure. One observable difference between the $l = 4$ (g.s.) and $l = 2$ (3.37 MeV) curves, displayed in Figs. 2 and 3, respectively, is the forward-angle behavior: The $l = 2$ curve tends to flatten out near 10°, while the $l = 4$ curve is much steeper. The 4.77-MeV level, assigned $l = 4$ by the ^{90}Zr(^{3}He, d) reaction,[2, 6] also shows a very steep angular distribution at forward angles (see Fig. 2). The 4.18-MeV level, whose angular

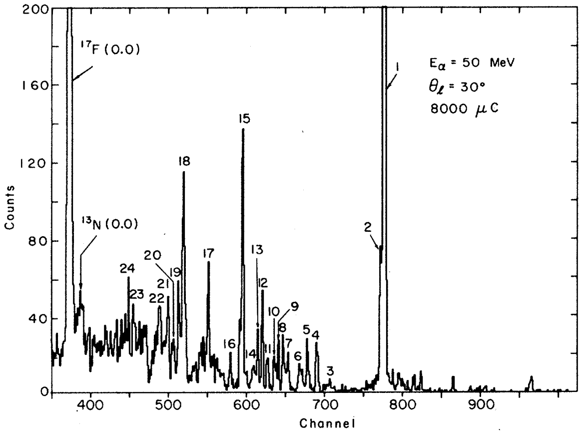

FIG. 1. Triton energy spectrum from the reaction ^{90}Zr(α, t)^{91}Nb at θ_l =30°.

distribution is shown in both Figs. 2 and 3, has been assigned[2,6] $l = 2$ (the l value is bracketed in Ref. 2). The (α, t) angular distribution agrees better with the $l = 4$ curves, although the differences are very slight.

A more serious discrepancy with the $l = 2$ assignment of the 4.18-MeV level comes from the strength of the state. The spectroscopic factors given for this level predict it to be weaker than the 3.37-MeV level by a factor of between 14 (Ref. 6) and 20 (Ref. 2), while the relative cross sections of the levels seen in the (α, t) data (Table II) show a difference of only a factor of 2. Thus, the 4.18-MeV level is between 7 and 10 times too strong to be consistent with the $l = 2$ spectroscopic factors of previous work.[2,6] This discrepancy seems rather large, since it has been verified[16] that (α, t) spectroscopic factors are, in general, the same as those obtained from (^{3}He, d) experiments (within about a factor of 2). Additional evidence for the existence of a high-spin state in this region comes from a recent study of the β decay of ^{91}Mo,[17] which indicates a weak level at 4.179 $\pm$0.001 MeV. A summary of the levels observed in the β decay is included in Table II. Since no intensity is given for the γ decay of the 4.179-MeV level, it is not possible to distinguish between an allowed and a first-forbidden electron-capture decay. For an allowed decay, final spins of $\frac{7}{2}^+$, $\frac{9}{2}^+$, or $\frac{11}{2}^+$ are possible, and for a first-forbidden transition $\frac{5}{2}^-$, $\frac{7}{2}^-$, $\frac{9}{2}^-$, $\frac{11}{2}^-$, or $\frac{13}{2}^-$ states are permitted. The shell model rules out the $\frac{11}{2}^+$, $\frac{9}{2}^-$, and $\frac{13}{2}^-$ possibilities, since the level is strongly populated in proton transfer. A $\frac{5}{2}^-$ assignment seems unlikely because the 4.179-MeV state is observed to decay only to the $\frac{9}{2}^+$ ground state.[17] There are at least two $\frac{5}{2}^-$ levels and a number of $\frac{3}{2}^-$ levels which should be fed from the decay of a $\frac{5}{2}^-$ state, while none are observed. A $\frac{7}{2}^-$ level strongly populated by the (α, t) reaction would presumably be an $f_{7/2}$ proton-hole state. However, in the available (d, ^{3}He) experiments in this mass region[3,18]

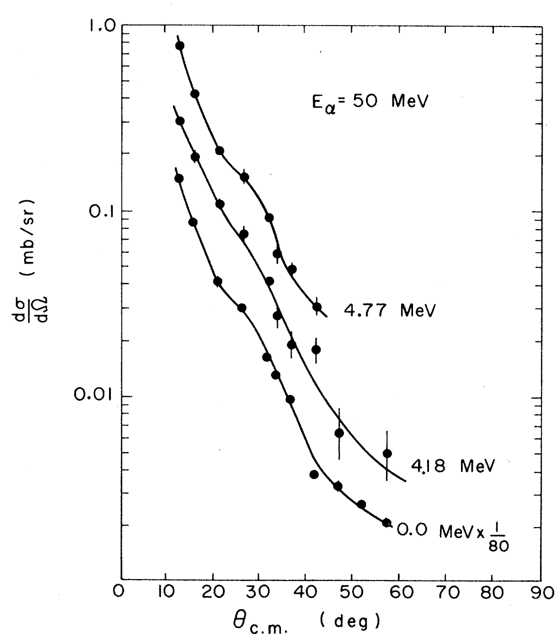

FIG. 2. Angular distributions of tritons from the reaction ^{90}Zr(α, t)^{91}Nb leading to the 0.0-, 4.18-, and 4.77-MeV levels. Statistical errors are shown for each point. The curves have no theoretical significance.

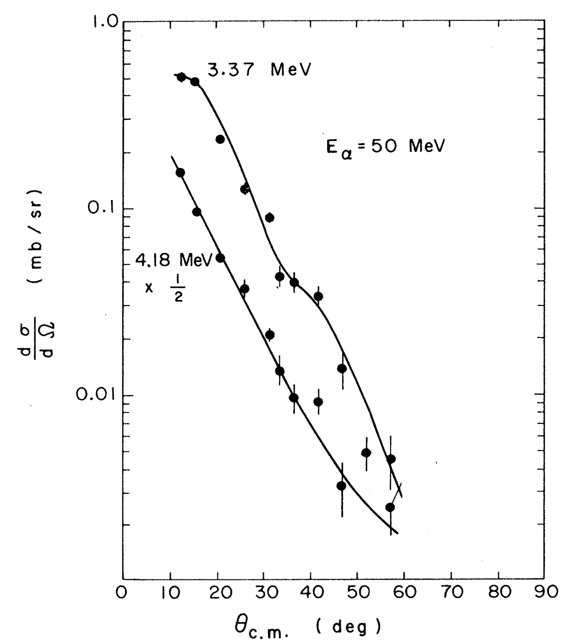

FIG. 3. Angular distributions of tritons from the reaction ^{90}Zr(α, t)^{91}Nb leading to the 3.37- and 4.18-MeV levels. Statistical errors are shown for each point. The curves have no theoretical significance.

no $f_{7/2}$ hole states were observed. The remaining choices, $\frac{7}{2}^+$, $\frac{9}{2}^+$, and $\frac{11}{2}^-$ are all equally consistent with the β-decay results.[17]

The 4.89-MeV level observed in the (α, t) experiment corresponds to an unassigned doublet at 4.85 and 4.90 MeV in Ref. 2. A level at 4.912 MeV was observed in a lower-energy experiment[6] and assigned $l=2$. The (α, t) angular distribution of the 4.89-MeV level (not shown) corresponds more closely to the $l=4$ shape and the strength of the state is too large relative to the 3.37-MeV level by a significant factor. The spectroscopic factor for this level would correspond to a cross section relative to the 3.37-MeV level of 1/16 instead of the observed intensity ratio of 1/2.3. Thus, the 4.89-MeV level is 7 times stronger than its $l=2$ assignment[6] would indicate. Unfortunately, the β decay of ^{91}Mo($\frac{9}{2}^+$)[17] can only populate ^{91}Nb levels up to about 4.4 MeV so it provides no additional information about the 4.89-MeV state.

In the excitation-energy region between 2.5 and 3 MeV there are several levels observed in (α, t) which appear either weakly[1,6] or not at all[2,4] in the (^{3}He, d) data. The many levels which are populated by both reactions make it seem likely that these "new" proton levels, e.g., 2.30, 2.39, 2.53, 2.61, 2.77, 2.90, and 3.01 MeV, appear in the ^{90}Zr(α, t)-^{91}Nb spectrum because they are high-angular-momentum transitions. The large value of $\vec{Q}\times\vec{R}$ (≈ 6) for the (α, t) reaction favors $l=4-6$ transfers, while the (^{3}He, d) reaction has the best momentum matching for $l=2-3$ transitions. Thus, states containing small amplitudes of, say, $g_{9/2}$, $g_{7/2}$, or $h_{11/2}$ strength would have larger cross sections in (α, t) than in (^{3}He, d). Of the six levels seen in the (α, t) experiment between 2.39 and 3.01 MeV, only the 2.90-MeV level was not reported in the β-decay study.[17] This supports our contention that these levels are high-spin states having at least some single-particle amplitude.

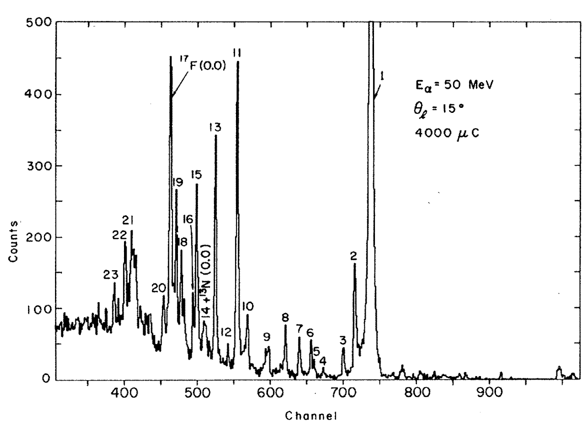

FIG. 4. Triton energy spectrum from the reaction ^{92}Mo$(\alpha, t)^{93}$Tc at $\theta_t = 15°$.

The 5.14-MeV level seen in (α, t) has an intensity relative to the 3.37-MeV level of about 1/3. Of the reported[2,6] levels in this region, only that at 5.24 MeV has a spectroscopic factor consistent with the intensity ratio from (α, t). However, the discrepancy in excitation energies between the (α, t) and (^{3}He, d) states is larger than the expected uncertainties, if both reactions are populating the same level.

The intensity of the $l=4$ level near 6 MeV seems rather low in the (α, t) data compared with the (^{3}He, d) spectroscopic factors.[2,6] Knöpfle *et al.*[6] show a cross-section ratio $\sigma(6.04)/\sigma(4.82)\approx 2$, while our data give $\sigma(5.95)/\sigma(4.77)\approx 1/2$. Unfortunately, the 6-MeV region of the spectrum is obscured at forward angles by the ^{17}F(g.s.) impurity peak, so the measured intensity of the 5.95-MeV level is only approximate. Whether the apparent difference in strength is related to the fact that the upper level is slightly unbound cannot be determined without distorted-wave Born-approximation (DWBA) calculations.

The appearance of probable high-angular-momentum transitions at 2.39, 2.53, 2.61, 2.77, 2.90, 3.01, 4.18, 4.77, 4.89, and (5.14) MeV is consistent with the general picture of the proton states in ^{91}Nb. It was pointed out in Ref. 2, for example, that the number of $g_{7/2}$ levels observed is much smaller than expected compared with the considerable fragmentation of the $l=0$ and $l=2$ levels. However, the two observed[2] $l=4$ transitions (at 4.80 and 6.01 MeV) already account for over 90% of the total $g_{7/2}$ strength so the appearance of these "extra" levels would require a renormalization of the spectroscopic strength if some of them are, in fact, $g_{7/2}$ fragments. Of course, another possible explanation for the strong levels in (α, t) is that they contain $h_{11/2}$ fragments. In this case our results would not be in contradiction with those from (^{3}He, d).[2]

B. ^{92}Mo$(\alpha, t)^{93}$Tc

A triton spectrum of the reaction ^{92}Mo$(\alpha, t)^{93}$Tc at $\theta_t = 15°$ is shown in Fig. 4. The resolution is 55 keV (FWHM). The intensity of the ground state ($g_{9/2}$) is again much greater than that of any other level in the spectrum. A summary of the levels observed in the reaction ^{92}Mo$(\alpha, t)^{93}$Tc compared with the ^{92}Mo(^{3}He, d) results[1,5] is given in Table III. The spectra were calibrated using the ^{17}F(g.s.) and ^{93}Tc(g.s.) peaks as a function of angle, with Q values obtained from Ref. 11. As can be seen from Table III, the excitation energies determined in this work agree well with those found previously,[1,5] with very few exceptions.

The largest energy discrepancy occurs for the (α, t) level at 3.10 ± 0.02 MeV, which may correspond to the $(^3He, d)$ state observed at 3.170 ± 0.02 [1] and 3.147 ± 0.015 [5] MeV. However, the $l=2$ spectroscopic factor for the 3.147-MeV level is only $\frac{1}{23}$ that of the 3.343-MeV level,[5] while the (α, t) intensity ratio, $\sigma(3.10)/\sigma(3.36)$, is about 1/4. Thus, the different values for the excitation energy may be due to population in (α, t), but not in $(^3He, d)$, of a high-spin state near the 3.15-MeV level.

The 0.68- and 2.14-MeV levels, both weakly populated in $(^3He, d)$, are relatively stronger in (α, t), which indicates high-angular-momentum assignments. The 2.13-MeV level was assigned $l=3$ ($f_{5/2}$) in Ref. 5, in agreement with the stronger population in (α, t). The 0.68-MeV state, which is quite weak even in (α, t), might correspond to a $\frac{7}{2}^+$ level calculated to be at about 0.7 MeV in ^{93}Tc.[7,8,19] Population of this level, which is mainly a $(\pi g_{9/2})^3{}_{7/2^+}$ configuration, would indicate some mixing with the $\pi g_{7/2}$ single-particle state.

In the ^{92}Mo$(\alpha, t)^{93}$Tc spectra, as was the case with ^{90}Zr$(\alpha, t)^{91}$Nb (see above), there is one level, at 3.91 MeV, whose strength is inconsistent with the $l=2$ assignment[1] from the $(^3He, d)$ reaction. (The 3.890-MeV level is also given a tentative $l=2$

TABLE III. Levels observed in the reaction ^{92}Mo$(\alpha, t)^{93}$Tc at 50 MeV.

No.	(α, t) Levels observed [c] (MeV)	(α, t) Intensity [d] (mb)	$(^3He, d)$ [a] Levels observed (MeV)	l_p	C^2S [e]	$(^3He, d)$ [b] Levels observed (MeV)	l_p	C^2S [e]
1	0.0	3.709	0.0	4	0.67	0.0	4	0.50
2	0.39	0.118	0.390 ± 0.010	1	0.30	0.396 ± 0.005	1	0.28
3	0.68	0.040	0.660 ± 0.020		Weak	(0.66)		Weak
4	1.18	0.019	1.190 ± 0.015	1	0.03, 0.01	1.21 ± 0.020	1	0.034, 0.015
5	1.42 ± 0.03	0.037						
6	1.51	0.044	1.500 ± 0.015	1	0.10, 0.04	1.500 ± 0.010	1	0.12, 0.052
7	1.78	0.055 [f]	1.780 ± 0.020	1	0.12, 0.05	1.788 ± 0.010	1	0.11, 0.048
8	2.14	0.097	2.130 ± 0.020		Weak	2.134 ± 0.015	3	0.045 [g]
9	2.59 ± 0.04	0.082	2.565 ± 0.020	2	0.04, 0.02	2.556 ± 0.015	2	0.037, 0.019
10	3.10	0.091						
			3.170 ± 0.020	(2)		3.147 ± 0.015	2	0.034, 0.018
11	3.36	0.390	3.360 ± 0.020	2	0.78, 0.38	3.343 ± 0.015	2	0.78, 0.41
12	3.58	0.064						
13	3.91	0.245	3.910 ± 0.020	2	0.09, 0.05	3.89 ± 0.020	(2)	(0.11, 0.06)
			4.110 ± 0.020	(0)	(0.15)	4.09 ± 0.030	0	0.23
14	4.15 ± 0.04	0.059 [f]						
15	4.37	0.192 [f]	4.43			4.39 ± 0.040		
16	4.47	0.066 [h]						
17	4.67 ± 0.03	0.07 [i]						
18	4.77 ± 0.03	0.087 [i]	4.79			4.76 ± 0.030		
19	4.90	0.166 [i]	4.92			4.88 ± 0.030		
			5.02					
20	5.20 ± 0.03	0.097 [h]	5.18			5.170 ± 0.015	1	0.23, 0.083
			5.33			5.302 ± 0.015	2	0.059, 0.032
			5.49			5.50 ± 0.040	(2)	(0.051, 0.028)
			5.65			5.64 ± 0.040	2	0.035, 0.019
21	6.01 ± 0.03	0.16 [h]				5.98 ± 0.040	(5)	(0.079) [j]
22	6.17 ± 0.03	0.17 [h]				6.24 ± 0.040		
23	6.44 ± 0.04	0.11 [h]						

[a] Taken from Ref. 1. No spectroscopic information is given for levels above 4.110 MeV.
[b] Taken from Ref. 5.
[c] Excitation energy ±20 keV except as noted.
[d] Integrated from $\theta_{c.m.} = 12.5$ to 57° except as noted.
[e] When two values are listed the first corresponds to $j = l - \frac{1}{2}$, the second to $j = l + \frac{1}{2}$.
[f] Integrated from $\theta_{c.m.} = 12.5$ to 52°.
[g] Assumed $f_{5/2}$.
[h] Integrated from $\theta_{c.m.} = 12.5$ to 36.5°.
[i] Integrated from $\theta_{c.m.} = 15.5$ to 52°.
[j] Assumed $h_{11/2}$.

assignment in Ref. 5, although it does not have a typical $l=2$ angular distribution. This may be an indication that there exist two closely spaced levels at this energy but Kozub and Youngblood[5] found no combination of two l values which would yield the observed shape.) The angular distribution of the 3.91-MeV level (Figs. 5 and 6) shows a forward-angle behavior similar to that of the ground state ($l=4$); it does not appear to flatten out at forward angles as does the 3.36-MeV level in ^{93}Tc (and the 3.37-MeV level in ^{91}Nb). As mentioned above, this difference in angular distributions is very slight and would certainly not allow a determination of the l transfer by itself. The spectroscopic factors for this level from the (^{3}He, d) experiments[1,5] predict it to be weaker than the 3.36-MeV level by a factor of about 7, while the ratio of (α, t) cross sections is about 1.6. The 3.91-MeV level observed in the ^{92}Mo(α, t) data is, therefore, about four times too strong to be consistent with the $l=2$ assignment of previous work.[1,5]

Around 4.5 MeV there are several levels (mostly doublets) which are more strongly excited by (α, t) than (^{3}He, d).[1,5] Thus they may be populated by $l>2$ transfers. The angular distributions of the 4.37- and 4.90-MeV states (Fig. 5) are similar to that of the $l=4$ ground-state transition. Moreover, Vourvopoulos *et al.*[2] found $l=4$ levels at about this excitation energy in ^{91}Nb.

The 5.98-MeV level seen in Ref. 5 probably corresponds to the multiplet at 6.01 MeV in the (α, t) data. The tentative $l=5$ assignment made by Kozub and Youngblood[5] for the 5.98-MeV state is in qualitative agreement with the observed strength of the 6.01-MeV multiplet in (α, t) (see Fig. 4). The (^{3}He, d) experiment[5] finds the $d_{5/2}$ analog state at 8.4 MeV, which corresponds to a splitting between $T_>$ and $T_<$ centroids of about 4.7 MeV for the $d_{5/2}$ configuration. Recent ^{92}Mo(d, p)^{93}Mo experiments[20,21] show the existence of an $h_{11/2}$ neutron level at 2.30 MeV. Assuming the same splitting between $T_>$ and $T_<$ states for the $h_{11/2}$ configuration in ^{93}Tc would then give 6.0 MeV as the expected location of the $T_<$ $l=5$ levels. The predicted $g_{7/2}$ centroid would be about 5.2 MeV (based on the neutron single-particle centroid from Ref. 20), but this is somewhat higher than the strong levels observed in our data. The data of Vourvopoulos *et al.*[2] indicate that the $T_>$-$T_<$ splitting is about 1 MeV larger for the $g_{7/2}$ states than it is for the $d_{5/2}$ states in ^{91}Nb and a similar difference in ^{93}Tc would predict a $g_{7/2}$ centroid in reasonable agreement with the observed strong levels in ^{93}Tc between 3.9 and 4.9 MeV.

It is interesting to note that the ^{90}Zr(d, p) and (α, ^{3}He) reactions[22] find the $g_{7/2}$ and $h_{11/2}$ centroids at the *same* energy in ^{91}Zr, which would suggest the existence of $T_<$ $l=5$ states near 5 to 6 MeV in ^{91}Nb as well as ^{93}Tc, although none have been observed. [The 6-MeV levels observed in ^{91}Nb are not as

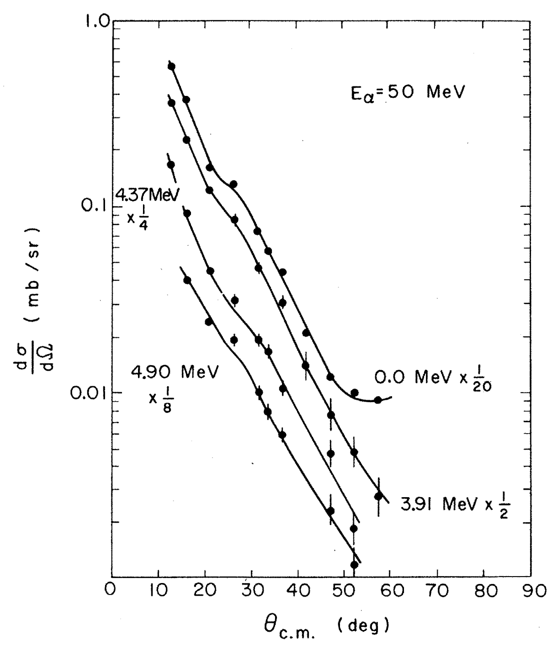

FIG. 5. Angular distributions of tritons from the reaction ^{92}Mo(α, t)^{93}Tc leading to the 0.0-, 3.91-, 4.37-, and 4.90-MeV levels. Statistical errors are shown for each point. The curves have no theoretical significance.

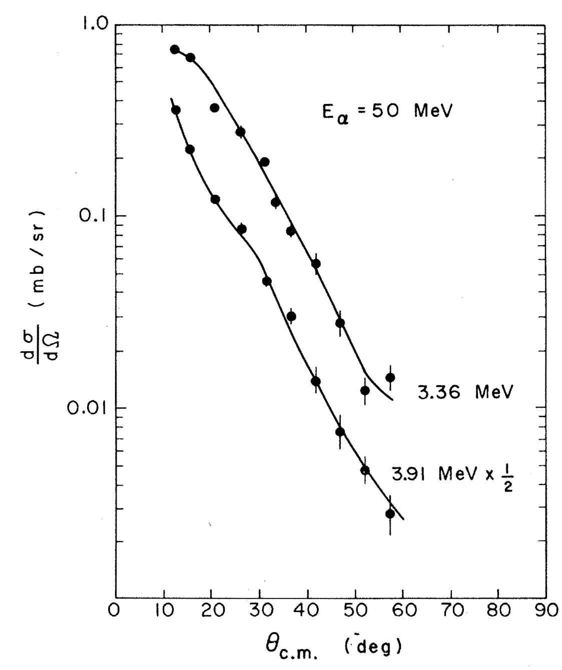

FIG. 6. Angular distributions of tritons from the reaction ^{92}Mo(α, t)^{93}Tc leading to the 3.36- and 3.91-MeV levels. Statistical errors are shown for each point. The curves have no theoretical significance.

strongly excited with (α, t) as those in ^{93}Tc and have been assigned $l=4$ by the (^{3}He, d) reaction.[2,6]]

IV. CONCLUSIONS

The reactions ^{90}Zr(α, t) and ^{92}Mo(α, t) have been used to search for high-spin ($l>2$) levels in ^{91}Nb and ^{93}Tc. Based on relative intensities of levels seen in both the (^{3}He, d) and (α, t) reactions, ^{91}Nb states at 2.39, 2.53, 2.61, 2.77, 2.90, 3.01, 4.18, 4.77, 4.89, and (5.14) MeV are probable candidates for levels with $l=3$, 4, or 5. The 4.18-MeV level is assigned $l=2$ from (^{3}He, d),[2,6] but the large (α, t) strength and β decay of ^{91}Mo($\frac{9}{2}^+$)[17] indicate a high spin for this level. Levels near 6 MeV appear rather weakly in (α, t) although a strong $l=4$ level was observed in the (^{3}He, d) experiments[2,6] at 6.01 MeV. From the position of the $h_{11/2}$ neutron centroid in ^{91}Zr it is expected that $l=5$ proton levels may also exist in the 5- to 6-MeV region of ^{91}Nb, which could provide an explanation for some of the stronger levels observed in the (α, t) data in this region.

Possible high-spin levels in ^{93}Tc include the 0.68-, (3.58-), 4.37-, (4.47-), (4.67-), 4.77-, 4.90-, 6.01-(multiplet), 6.17-, and 6.44-MeV states. The states above 6 MeV may be $l=5$ levels based on tentative results from the (^{3}He, d) experiment of Kozub and Youngblood.[5] The 3.91-MeV level, assigned $l=2$ from the (^{3}He, d) studies,[1,5] is populated too strongly in (α, t) to be consistent with the measured spectroscopic factors and is believed to have $l>2$.

The Q value used in our analysis of the reaction ^{90}Zr$(\alpha, t)^{91}$Nb, −14.643 MeV, corresponds to a change in the ^{91}Nb mass excess of +98 keV. This change is roughly consistent with a new Q value determined for the ^{91}Zr(p, n) reaction[13] but contradicts a recent measurement of the ^{90}Zr(^{3}He, d)-^{91}Nb Q value[6] which confirms the ^{91}Nb mass excess of Mattauch, Thiele, and Wapstra.[12]

V. ACKNOWLEDGMENTS

We thank J. D. Sherman for his help with the experiment and C. Maples for allowing us to use his computer code LORNA for some of the data analysis. We also are indebted to C. Ellsworth for preparing the targets.

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

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