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Experimental Study of the (d,He^3) Reaction on Even-A Isotopes of Mo*

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The (d,He^3) reactions on Mo^{92,94,96,98} and the Mo^{92}(He^3,d) reaction were studied with 23-MeV deuterons and 34-MeV He^3 particles from the Argonne cyclotron. Experimental angular distributions were analyzed on the basis of the distorted-wave Born-approximation theory to determine the l values and spectroscopic factors. Results were compared with previous data and the shell-model predictions. Experimental strengths of the $g_{9/2}$ and $p_{1/2}$ components in the ground state of Mo^{92} are consistent with the calculations. Very low-lying states with large $p_{3/2}$ and $f_{5/2}$ strength were observed.

I. INTRODUCTION

THE structure of nuclei in the region of $Z=40$ has been studied theoretically by many authors.[1,2] In these calculations, a $_{38}\text{Sr}_{50}{}^{88}$ core is assumed and additional protons are put in the $p_{1/2}$ and $g_{9/2}$ orbits, while the additional neutrons are usually assumed to be in the $d_{5/2}$ orbit. The proton configuration of the ground state of Zr^{90} was extensively studied by various experiments,[3] including (d,He^3), (He^3,d), and (p,α) reactions. The results seem to support the theory. Recently, the (d,He^3) reaction on even-even Zr isotopes was investigated in detail by Preedom *et al.*[4] They obtained the $(p_{1/2})^2$ and $(g_{9/2})^2$ strength in the ground states of these isotopes from the experimental spectroscopic factors, and showed that the agreement with the theory was good. It is noticeable, however, that the low-lying $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states of Y isotopes have large single-particle components, while the energies of these states are well reproduced[1] by calculations in which a Sr^{88} core is assumed. In order to accumulate more spectroscopic information in this region, the (d,He^3) reactions on the even-even Mo isotopes were investigated. The Mo^{92}(He^3,d) reaction was studied at the same time to confirm the (d,He^3) results.

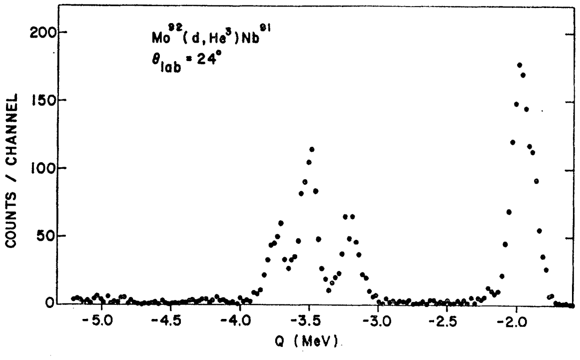

FIG. 1. Spectrum of He^3 particles from the Mo^{92}(d,He^3)Nb^{91} reaction.

II. EXPERIMENTAL PROCEDURES AND ANALYSIS

The experiments were done in the 60-in. scattering chamber[5] with the 23-MeV deuteron beam and the 34-MeV He^3 beam of the Argonne cyclotron. The energy spread of the incident beams after magnetic analysis was approximately 0.1%. A (dE/dx)-E telescope consisting of surface-barrier Si detectors was used for particle detection. Self-supporting metallic Mo foils, usually 500–1000 μg/cm^2 thick and enriched to 93–99% were used. Typical spectra obtained are shown in Figs. 1–5. The over-all resolution width was about 100–150 keV and was mainly due to the target thickness. The peak-shape-fitting program was used to analyze spectra when it was necessary. Uncertainties in the excitation energies obtained are less than 40 keV in most cases. In order to obtain the absolute cross sections, the angular distribution of elastically scattered deuterons from each target was measured and compared with the angular distribution calculated by the deuteron optical-model potential used in the distorted-wave Born-approximation (DWBA) calculations discussed below. Agreement between the shapes of the measured and calculated angular distributions was very good, and the correction

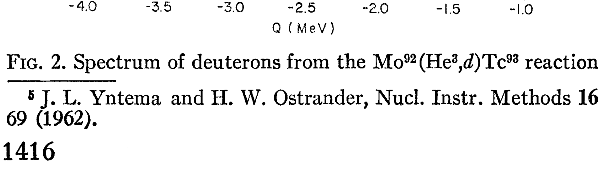

FIG. 2. Spectrum of deuterons from the Mo^{92}(He^3,d)Tc^{93} reaction.

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

[1] I. Talmi and I. Unna, Nucl. Phys. **19**, 225 (1960); N. Auerbach and I. Talmi, *ibid.* **64**, 458 (1965); J. Vervier, *ibid.* **75**, 17 (1966).

[2] S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga, Phys. Letters **10**, 195 (1964).

[3] S. Bjornholm, O. B. Nielsen, and R. K. Sheline, Phys. Rev. **115**, 1613 (1959); J. L. Yntema, Phys. Letters **11**, 140 (1964); R. B. Day, A. G. Blair, and D. D. Armstrong, *ibid.* **9**, 327 (1964); C. B. Fulmer and J. B. Ball, Phys. Rev. **140**, B331 (1965).

[4] B. M. Preedom, E. Newman, and J. C. Hiebert, Phys. Rev. **166**, 1156 (1968).

[5] J. L. Yntema and H. W. Ostrander, Nucl. Instr. Methods **16**, 69 (1962).

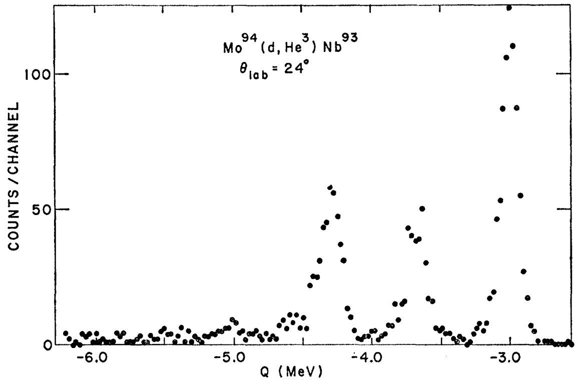

FIG. 3. Spectrum of He^3 particles from the Mo^{94}(d,He^3)Nb^{93} reaction.

factors for the target thicknesses were obtained by comparing the absolute cross sections. Errors in the absolute cross sections obtained for the (d,He^3) reactions are estimated to be about 25%.

Experimental angular distributions of the reaction products were compared with the DWBA theory. The optical-model parameters used in the DWBA calculations are listed in Table I. The deuteron parameters are the same as were used[6] to fit the elastic scattering on Fe^{54} between 14 and 18 MeV. The He^3 parameters are virtually the same as those obtained by Bassel[7] except that we used a volume absorption with a larger radius instead of using both volume and surface absorptions. The bound-state parameters used are $r_0 = 1.2$ F, $r_c = 1.4$ F, $a = 0.65$ F, and $\lambda_{so} = 25$. The normalization factors used here are 2.6 for the (d,He^3) reaction and 3.84 for the (He^3,d) reaction.[8] Zero-range local, finite-range local, zero-range nonlocal, and finite-range nonlocal calculations (with the local-energy approximation[9]) were tried with nonlocalities $\beta(d) = 0.54$, $\beta(\mathrm{He}^3,d) = 0.2$, and $\beta(p) = 0.85$, and the range parameter 1.54 F. Cross sections calculated with different sets of assumptions may differ by almost 50% although there are only small changes in the shapes of the angular distributions and the relative values of spectroscopic factors. Spectroscopic factors given in Table II are those obtained by zero-range nonlocal calculations because they consistently give spectroscopic factors for the ground state and first excited state close to the sum-rule limits.

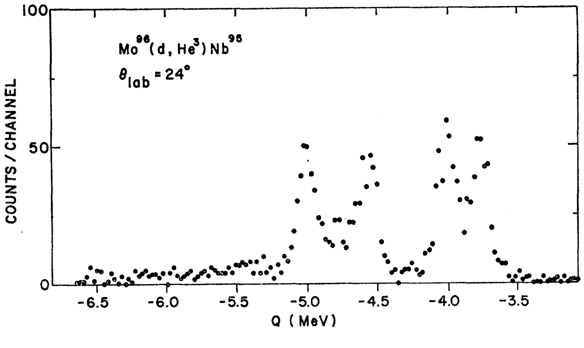

FIG. 4. Spectrum of He^3 particles from the Mo^{96}(d,He^3)Nb^{95} reaction.

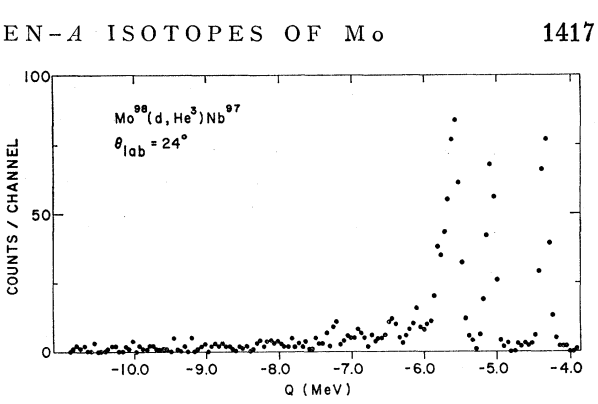

FIG. 5. Spectrum of He^3 particles from the Mo^{98}(d,He^3)Nb^{97} reaction.

III. RESULTS

Mo^{92}

The angular distributions for the Mo^{92}(d,He^3)Nb^{91} and Mo^{92}(He^3,d)Tc^{93} reactions are shown in Figs. 6 and 7, respectively. Both final nuclei are known[10] to have a ground state and a first excited state with spins and parities $\frac{9}{2}^+$ and $\frac{1}{2}^-$, respectively. The angular distributions for these states are well fitted by the DWBA calculations with a $g_{9/2}$ and $p_{1/2}$ proton transfer, respectively.

In addition to these levels, several states in Nb^{91} are also known.[10,11] Among them, two states at 1.31 and 1.62 MeV were assigned to be $\frac{1}{2}^-$ or $\frac{3}{2}^-$ since they are directly populated by the β decay of the metastable state of Mo^{91}. Both states are strongly excited by the (d,He^3) reaction and have an $l = 1$ angular distribution, but the minimum near 20° in each angular distribution is shallower than that of the distribution for the first excited state. The $p_{1/2}$ strength is almost exhausted by the first excited state; the two higher states are there-

TABLE I. Optical-model parameters used in the DWBA calculations.

Projectile	V (MeV)	W (MeV)	r_0 (F)	a (F)	r' (F)	a' (F)	W' (MeV)	V_{so} (MeV)	r_c (F)
d	105	···	1.06	0.86	1.42	0.65	54	6.0	1.3
He^3	173	18	1.14	0.723	1.65	0.8	···	···	1.4

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[6] J. L. Yntema, H. Ohnuma, and H. T. Fortune, Bull. Am. Phys. Soc. 13, 699 (1968).

[7] R. H. Bassel (private communication).

[8] R. H. Bassel, Phys. Rev. 149, 791 (1966).

[9] F. G. Perey and B. Buck, Nucl. Phys. 32, 353 (1962); F. G. Perey and D. S. Saxon, Phys. Letters 10, 107 (1964).

[10] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington, D. C. 20025, 1960), NRC 60-5-70, 91, 119, 43.

[11] Von T. Cretzu, K. Hohmuth, and J. Schintlmeister, Ann. Physik 16, 312 (1965); G. Bassani, J. Picard, and G. Souchère, in *International Conference on Nuclear Structure, Tokyo, 1967* (Institute for Nuclear Study, University of Tokyo, Tokyo, 1967), p. 126.

fore probably $p_{3/2}$ hole states. The difference between the $p_{1/2}$ and $p_{3/2}$ angular distributions is attributed to the j dependence of the $l=1$ transition.[12] Another state in Nb^{91} was seen at 1.85 MeV in this experiment. This state is excited by an $l=3$ proton pickup and is most likely $\frac{5}{2}^-$. The only strongly excited states in Tc^{93} observed in the (He^3,d) reaction are the ground state and the first excited state.

TABLE II. Summary of the present experiment and comparison with previous data.

	Present results				Previous data		
Nucleus	Q	E_{exc}	J^π	C^2S	E_{exc}	J^π	Ref.
Nb^{91}	−1.85	0	$\frac{9}{2}^+$	2.7	0	$\frac{9}{2}^+$	
	−1.95	0.10	$\frac{1}{2}^-$	1.4	0.104	$\frac{1}{2}^-$	
					0.800	$\frac{7}{2}^+, \frac{9}{2}^+$	a
					1.040	$\frac{7}{2}^+, \frac{9}{2}^+$	
	−3.16	1.31	$(\frac{3}{2}^-)$	1.1	1.310	$\frac{1}{2}^-, \frac{3}{2}^-$	
					1.600	$\frac{7}{2}, \frac{9}{2}, \frac{11}{2}$	
	−3.47	1.62	$(\frac{3}{2}^-)$	2.3	1.640	$\frac{1}{2}^-, \frac{3}{2}^-$	
	−3.70	1.85	$\frac{5}{2}^-$	4.9			
Nb^{93}	−3.00	0	$\frac{9}{2}^+$	(2.9)	0	$\frac{9}{2}^+$	
	−3.03	0.03	$\frac{1}{2}^-$	(1.6)	0.029	$\frac{1}{2}^-$	
	−3.68	0.68	$(\frac{3}{2}^-)$	1.2			
					0.741	$(\frac{7}{2})$	
					0.809	$(\frac{5}{2})$	
					0.958	$(\frac{9}{2}^+)$	b
					1.08	$(\frac{5}{2}, \frac{7}{2})$	
					1.17		
					1.28		
	−4.32	1.32	$(\frac{3}{2}^-)$	(1.9)	1.34		
	−4.32	1.32	$(\frac{5}{2}^-)$	(3.5)			
					1.48		
					1.67		
					1.92		
Nb^{95}	−3.81	0	$\frac{9}{2}^+$	2.9	0	$\frac{9}{2}^+$	
	−4.04	0.23	$\frac{1}{2}^-$	1.6	0.237	$\frac{1}{2}^-$	c
					0.726	$(\frac{7}{2}^+)$	
					0.757	$(\frac{7}{2}^+)$	
	−4.58	0.77	$(\frac{3}{2}^-)$	1.8			
	−4.79	0.98	$\frac{5}{2}^-$	2.1			
	−5.03	1.22	$(\frac{3}{2}^-)$	(2.4)			
Nb^{97}	−4.30	0	$\frac{9}{2}^+$	2.2	0	$\frac{9}{2}^+$	
	−5.04	0.74	$\frac{1}{2}^-$	1.1	0.743	$\frac{1}{2}^-$	
					1.148	$(\frac{5}{2}^+, \frac{7}{2}^\pm)$	
	−5.54	1.24	$(\frac{3}{2}^-)$	2.5	1.251		
					1.276	$(\frac{5}{2}^+, \frac{7}{2}^\pm)$	
	−5.72	1.42	$(\frac{5}{2}^-)$	2.5	1.434		d
					1.548		
					1.653		
					1.750	$(\frac{3}{2}, \frac{5}{2}^-)$	
					1.764		
					1.852	$(\frac{3}{2}, \frac{5}{2}^-)$	
					2.106	$(\frac{1}{2}, \frac{3}{2}^+)$	
					2.247		
Tc^{93}	−1.41	0	$\frac{9}{2}^+$	0.69	0	$\frac{9}{2}^+$	
	−1.80	0.39	$\frac{1}{2}^-$	0.34	0.390	$\frac{1}{2}^-$	e

[a] References 10, 11.
[b] References 10, 14.
[c] References 10, 15.
[d] References 10, 16.
[e] Reference 10.

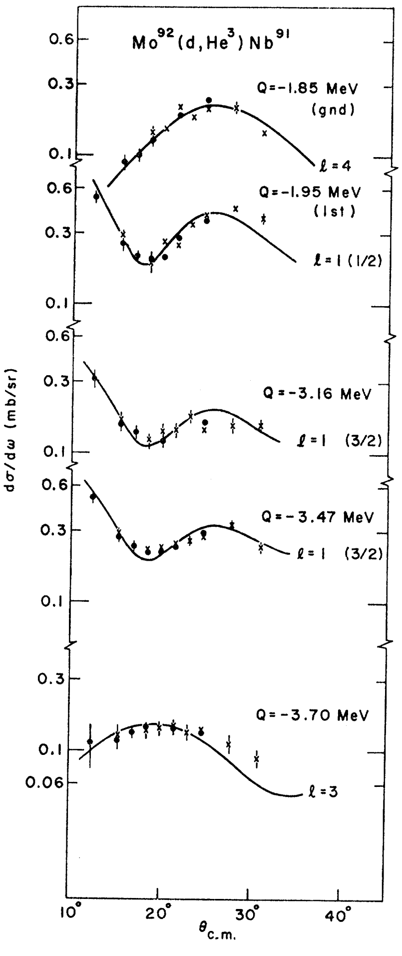

FIG. 6. The angular distributions obtained for the $Mo^{92}(d,He^3)Nb^{91}$ reaction. The solid lines are DWBA predictions.

Mo^{94}

The $\frac{1}{2}^-$ first excited state of Nb^{93} is only 29 keV above the $\frac{9}{2}^+$ ground state, and was not resolved in the present experiment. However, the respective contributions from the ground state and first excited state were separated by comparing the unresolved angular distributions with the experimental angular distributions of Nb^{91} and Nb^{95} and with the DWBA predictions for Nb^{93}. These separate contributions are shown as dashed lines in Fig. 8. Spectroscopic factors were obtained from these curves.

An $l=1$ transition to a state at 0.68 MeV was observed and assigned to be $\frac{3}{2}^-$ on the basis of the shape and the spectroscopic factor as before. Another peak at 1.32 MeV is always broader than the others and may be considered to be a doublet consisting of an $l=1$ transition and probably an $l=3$ transition. Again the spectroscopic factor indicates a $\frac{3}{2}^-$ assignment for this

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[12] H. Ohnuma and J. L. Yntema (to be published).

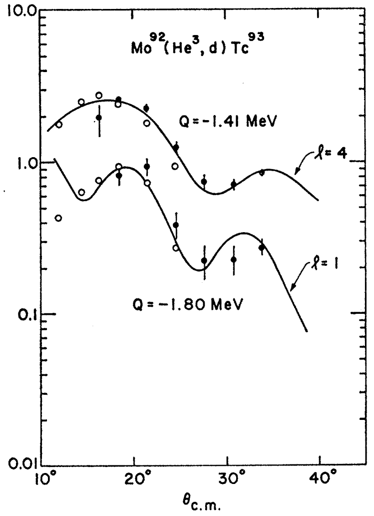

FIG. 7. The angular distributions obtained for the Mo^{92}(He^3,d)Tc^{93} reaction. The solid lines are DWBA predictions.

transition. As before, the decomposed angular distributions are shown dashed in Fig. 8, the solid curve represents their sum, and the points are the experimental results.

Mo^{96}

Angular distributions from reactions leading to the ground state and first excited state of Nb^{95} are in agreement with the calculated curves of the $g_{9/2}$ and $p_{1/2}$ proton pickups, respectively, as shown in Fig. 9. A transition to a state at 0.77 MeV has an $l=1$ character, and the spin and parity of this level is probably $\frac{3}{2}^-$. An $l=3$ angular distribution gives the best fit to the transition to the state at 0.98 MeV. The fifth transition shows a rather flat distribution, and may be a mixture of angular distributions corresponding to different l values.

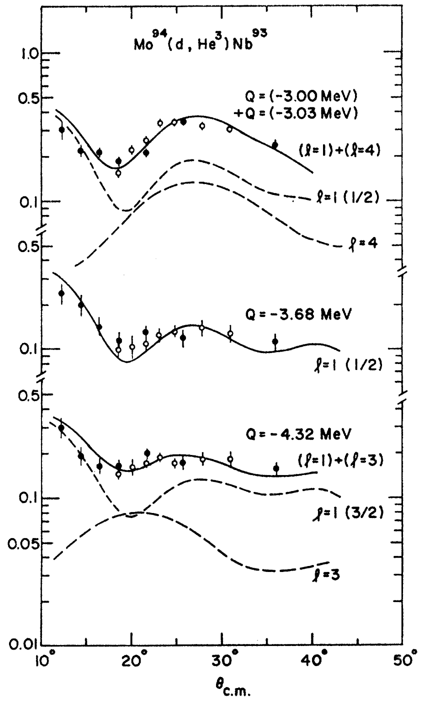

FIG. 8. The angular distributions obtained for the Mo^{94}(d,He^3)-Nb^{93} reaction. The solid and dashed lines are DWBA predictions. The solid lines for the mixed transitions are sums of the two dashed lines.

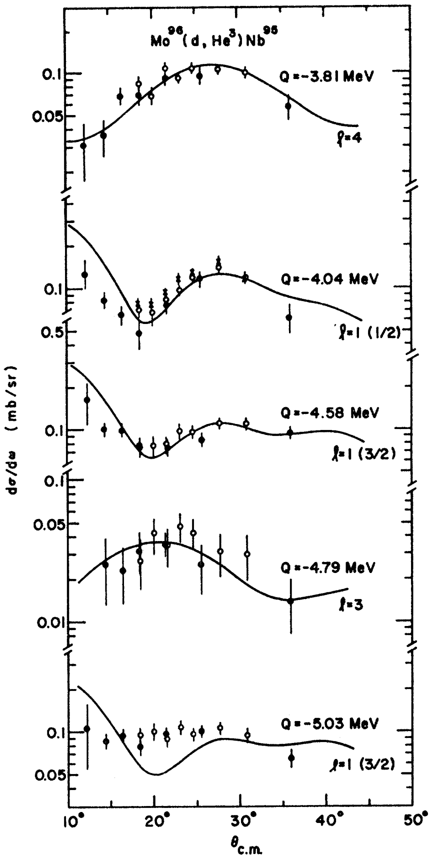

FIG. 9. The angular distributions obtained for the Mo^{96}(d,He^3)Nb^{95} reaction. The solid lines are DWBA predictions.

Mo^{98}

Figure 10 shows the angular distributions for the Mo^{98}(d,He^3)Nb^{97} reaction. The present results are in good agreement with the $\frac{9}{2}^+$ and $\frac{1}{2}^-$ assignments for the ground state and first excited state. An $l=1$ transition to the 1.24-MeV state is observed. It appears to have a flatter angular distribution than that for the spin and parity $l=1$, $j=\frac{1}{2}$, and, considering the large spectroscopic factor, a $\frac{3}{2}^-$ assignment is more likely than $\frac{1}{2}^-$. The transition to the 1.42-MeV state is fitted best by an $l=3$ transfer, although there is some ambiguity because this state is not well separated from the 1.24-MeV state and has a relatively small cross section. The $\frac{3}{2}^-$ and $\frac{5}{2}^-$ assignments for the 1.24- and 1.42-MeV states, respectively, are consistent with the recent experiment on the β decay of Zr^{97}—as discussed in Sec. IV.

IV. DISCUSSION

The ground-state proton configuration of Mo isotopes may be described by the wave function

$$a[(p_{1/2}{}^2)_0(g_{9/2}{}^2)_0]+b[(g_{9/2}{}^4)_0].$$

Then the spectroscopic factor of the $p_{1/2}$ proton pickups is proportional to a^2, and that of the $p_{1/2}$ proton stripping to b^2. In the case of Mo^{92}, one obtains $a^2=0.7$ from the experimental value $C^2S_{p_{1/2}}(d,\mathrm{He}^3)=1.4$, and therefore $b^2=0.3$, which is in good agreement with the value found for $C^2S_{p_{1/2}}(\mathrm{He}^3,d)$. These values are close to the amplitudes[3,4] for the similar configuration of the ground state of Zr^{90}. Shell-model predictions[1,2] give roughly 60% $p_{1/2}{}^2$+40% $g_{9/2}{}^2$ for the ground state of Zr^{90}, and 70% $p_{1/2}{}^2g_{7/2}{}^2$+30% $g_{9/2}{}^4$ for that of Mo^{92}. This shows that the amplitude of the pure g configuration should decrease as the proton number increases from 40 to 42. Ambiguities in both experimental and theoretical results make it uncertain whether such an effect really exists.

The ground-state configuration of the Nb^{91} and Tc^{93} may similarly be expressed as $c(p_{1/2}{}^2)_0g_{9/2}+d(g_{9/2}{}^3)_{v=1}$ and $e(p_{1/2}{}^2)_0(g_{9/2}{}^3)_{v=1}+f(g_{9/2}{}^5)_{v=1}$, respectively, where $c^2\approx0.7$, $d^2\approx0.3$, $e^2\approx0.8$, and $f^2\approx0.2$ according to the shell-model calculations.[1] From these values one obtains $C^2S_{g_{9/2}}(d,\mathrm{He}^3)\approx2.5$ and $C^2S_{g_{9/2}}(\mathrm{He}^3,d)\approx0.74$. These results are in excellent agreement with experiment.

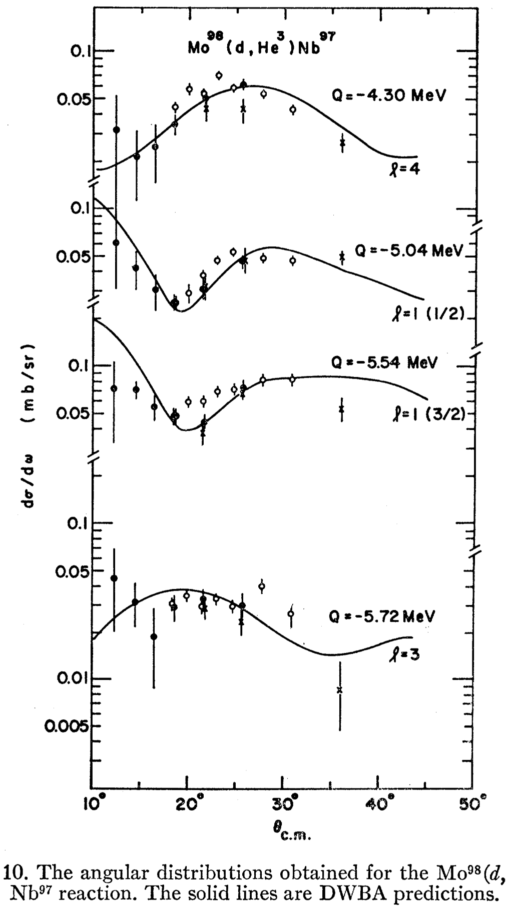

FIG. 10. The angular distributions obtained for the Mo^{98}(d,He^3)-Nb^{97} reaction. The solid lines are DWBA predictions.

Cohen *et al.*[2] showed that the admixture of the higher-seniority configurations is very small in the ground-state wave functions of $N=50$ nuclei, so that the above assumptions may be fairly good. For the Mo^{92}(d,He^3)-Nb^{91} reaction, the spectroscopic factors calculated[13] from their wave functions are 2.54 for the reaction to the ground state, 1.36 for that to the first excited state, and 0.10 for the one to another $\frac{9}{2}^+$ state at 1.656 MeV. These values are very close to the experimental values. Of course the second $\frac{9}{2}^+$ state is almost impossible to observe experimentally.

It was observed[4] that the relative amplitudes of the $(p_{1/2})^2$ and $(g_{9/2})^2$ configuration in the ground states of even-even Zr isotopes may depend on the mass number. The mass-number dependence of the similar amplitudes of the $(p_{1/2}{}^2g_{9/2}{}^2)$ and $(g_{9/2})^4$ configurations could not be observed within the experimental errors in the present experiment.

It is remarkable that states with large $p_{3/2}$ and $f_{5/2}$ strengths are found at low excitation energies in the Nb isotopes as well as in the Y isotopes.[4] This implies that one cannot ignore the $p_{3/2}$ and $f_{5/2}$ configurations even when low-lying states (excitation energies below about 1.5 MeV) are discussed. The experimentally observed total $p_{3/2}$ strengths are close to the sum-rule limit in most cases, but about 50% of the $f_{5/2}$ strengths are usually missing. This is presumably due to the $f_{5/2}$ strengths being fragmented among more levels than is the distribution of $p_{3/2}$ strength.

Two states of Nb^{91} at 1.31 and 1.62 MeV are assigned to have spin and parity $\frac{3}{2}^-$ as mentioned before. The known level at 0.958 MeV was not seen in the present experiment, although a $\frac{9}{2}^+$ assignment for this level is most likely from the results of the neutrons scattering and Coulomb excitation.[14] An upper limit of the value of C^2S for this level is estimated to be 0.3. A few states are known to exist[9,13] around 1.3 MeV in Nb^{93}, but the correspondence of the levels to the ones observed in the present experiment is ambiguous because no spin assignment has been made for these states. There are two known states in Nb^{95} besides the ground state and the first excited state. They are at 0.726 and 0.760 MeV, and both of them are assigned[15] to be $\frac{7}{2}^+$. Therefore the 0.77-MeV state observed here is not the one observed before.

Recently the β decay of Zr^{97} was studied extensively by Siivola and Graeffe.[16] They found a state at 1.251

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[13] R. D. Lawson (private communication).

[14] C. A. Engelbrecht, Phys. Letters 4, 213 (1963); D. Reitman, C. A. Engelbrecht, and A. B. Smith, Nucl. Phys. 48, 593 (1963); G. M. Gusinskii and I. H. Lemberg, Izv. Akad. Nauk SSSR, Ser. Fiz. **30**, 449 (1966).

[15] W. Collins, H. Daniel, and H. Schmidt, Ann. Physik **15**, 383 (1965); N. A. Eissa, Z. Meligg, A. H. El Farrash, and S. Girgis, Acta Phys. Acad. Sci. Hung. **23**, 67 (1967).

[16] A. Siivola and G. Graeffe, Nucl. Phys. **A109**, 369 (1968).

MeV in Nb^{97} which decays strongly to the first excited state. The logft value of the β decay of the Zr^{97}($\frac{1}{2}^+$) to this state is 8.1, which suggests that this is a hindered first-forbidden transition. These results are consistent with the conclusion from the present experiment that this level is mainly a $p_{3/2}$ proton-hole state. A $p_{3/2}$ proton-hole state should decay strongly to the $p_{1/2}$ first excited state. The β decay to such a state is first forbidden; it is permitted only when there is a ground-state correlation. Therefore the β decay would mainly go to the mixed configuration and would be somewhat hindered. The 1.42-MeV state observed here may correspond to the 1.434-MeV state seen in the β decay. Although the evidence is not unambiguous in this case, a $\frac{5}{2}^-$ assignment can explain why this state decays to the first excited state rather than to the ground state.

ACKNOWLEDGMENTS

We are indebted to Dr. R. M. Drisko for a copy of the code JULIE used in the distorted-wave calculation. The targets were prepared by F. J. Karasek. The technical assistance of J. Bicek and the cooperation of the cyclotron group is gratefully appreciated. One of the authors (H.O.) acknowledges financial support from the Sakkokai Foundation.

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Neutron Resonances of Th^{230}†

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The total neutron cross section of Th^{230} has been studied from 0.05 to about 500 eV with the Argonne fast chopper. Resonance parameters are given for many of the approximately 20 resonances observed below 300 eV. The value of the s-wave neutron strength function, based on these parameters, is $S_0 = (1.3_{-0.3}^{+0.6}) \times 10^{-4}$. The radiation width is $\Gamma_\gamma = 24 \pm 2$ meV. A calculation of the resonance-capture integral leads to the value 1020±30 b. Comparing this result with a direct measurement of the resonance-capture integral supports the value of 75 200 yr for the half-life of Th^{230} used in the derivation of the latter.

THE neutron resonances of Th^{230} have been studied from 0.05 to about 500 eV with the Argonne fast chopper.[1] The measurements were initiated to add to the still meager amount of data available on neutron interactions with heavy nuclides and to allow more positive isotopic identification of the resonances in a sample of Th^{229} studied earlier.[2] The latter had a 0.2% impurity of Th^{230}. With regard to this latter problem, it appears that only one resonance in Th^{229} coincides in energy with one in Th^{230}, so that a correction is needed only for the relatively weak resonance reported at 1.42 eV in Th^{229}. That the entire resonance effect is not associated with Th^{230} is made clear by the fact that the transmission dip is too large and by the fact that a peak appears at this energy in the fission cross section[3] of Th^{229}.

The measurements were made with Rotor No. III[4] of the Argonne fast chopper; neutron flight paths of 25 and 60 m were used, and the data were stored in a 1024-channel time analyzer.[5] The best time-of-flight resolution was about 35 nsec/m with the 60-m flight path.

Two samples of thorium were used in the study. Most of the measurements were made with a sample thickness of 1.04±0.05 g/cm^2 of Th^{230}, the thickest sample available. A thinner sample (with a maximum thickness of 0.0420±0.0008 g/cm^2 of Th^{230}) was used in additional measurements on several of the strong resonances at low energy. The samples were encapsulated as described in the earlier work[6] on curium and hence the thickness could be changed by rotating the capsule in the collimator. The thinnest sample used had a thickness of 0.0051 g(Th^{230})/cm^2. Both samples of thorium were made from the same batch of material for which the molar ratio of Th^{232} to Th^{230} is 0.109±0.001. The thickness of the thick sample was determined by measuring the area under the transmission dip resulting from the resonance at 21.80 eV in Th^{232}. The area, as determined in several independent measurements, was combined with the resonance parameters given by Shwe *et al.*[7]

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[1] L. M. Bollinger, R. E. Coté, and G. E. Thomas, in *Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958* (United Nations, Geneva, 1958), Vol. 14, p. 239.

[2] R. E. Coté, H. Diamond, and J. E. Gindler, Bull. Am. Phys. Soc. **6**, 417 (1961).

[3] L. M. Bollinger, H. Diamond, and J. E. Gindler, Bull. Am. Phys. Soc. **8**, 370 (1963).

[4] L. M. Bollinger, R. E. Coté, and G. E. Thomas, Argonne National Laboratory Report No. ANL-6169, 1960, p. 1 (unpublished).

[5] R. W. Schumann, Rev. Sci. Instr. **28**, 489 (1957).

[6] R. E. Coté, R. F. Barnes, and H. Diamond, Phys. Rev. **134**, B1281 (1964).

[7] Hla Shwe, G. E. Thomas, and L. M. Bollinger, Bull. Am. Phys. Soc. **13**, 722 (1968).