dipole strength in the giant resonance, and have several interesting features. The mode associated with the nuclear symmetry axis $\sigma_{||}$ appears to be a doublet, the higher component of which may be a vibrational satellite predicted by the dynamic collective model. The other mode $\sigma_{\perp}$ has a broad base but a sharp peak, suggesting a distribution of dipole strengths somewhat different than that calculated from either of the collective models discussed.

ACKNOWLEDGMENTS

The authors wish to thank Mark Carpenter, Jerry Sawyer, and Dr. J. T. Caldwell for their assistance while the data were being taken, James Nutter and the Linac mechanical technicians for their help with the polarized target, and E. Dante and the Linac operators for their help in performing the experiment. Comments and suggestions about the manuscript received from Dr. H. Arenhövel are also greatly appreciated.

PHYSICAL REVIEW VOLUME 179, NUMBER 4 20 MARCH 1969

Study of the $Zr^{94}(He^3, d)Nb^{95}$ Reaction*

H. Ohnuma† and J. L. Yntema
Argonne National Laboratory, Argonne, Illinois 60439

(Received 25 November 1968)

The $Zr^{94}(He^3, d)Nb^{95}$ reaction was studied with 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. The results are compared with the previous data on the (d, He^3) reactions on Mo and Zr isotopes, and the proton configurations of the nuclei in this region are discussed.

I. INTRODUCTION

The proton structure of nuclei in the region near $N=50$ has been extensively studied, mainly by single-nucleon stripping and pickup reactions.[1–3] The results seem to support the shell-model calculations[4,5] with the assumptions of the Sr^{88} core, in spite of the fact that states with large $p_{3/2}$ and $f_{5/2}$ strength were observed[2,3] at very low excitation energies. It may be interesting to study the (He^3, d) reactions on the nuclei in this region in order to compare the results with those from (d, He^3) reactions. In this paper the results of the $Zr^{94}(He^3, d)Nb^{95}$ reaction are reported.

II. EXPERIMENTAL PROCEDURES AND ANALYSIS

Details of the experiments and analysis were given in the previous paper[3] and will not be repeated here. The experiments were done in the 60-in. scattering chamber[6] with the 34-MeV He^3 beam of the Argonne cyclotron. A (dE/dx)-E telescope consisting of surface-barrier silicon detectors was used for particle detection. Self-supporting metallic zirconium foils, 960 $\mu g/cm^2$ thick and enriched to 95% in Zr^{94}, were used. The angular distributions obtained were compared with distorted-wave Born-approximation (DWBA) calculations performed with the code JULIE[7] and the optical-model parameters listed in Table I. The normalization factor[8] used was 3.84.

III. RESULTS AND DISCUSSION

A typical deuteron spectrum of 20° is shown in Fig. 1. Angular distributions for the low-lying states of Nb^{95} are given in Fig. 2, where the solid and dashed curves show the DWBA calculations. For unresolved states, solid curves represent the sums of two dashed lines. Separation of the angular distributions in the latter cases was found rather difficult and unreliable; since both $l=1$ and $l=4$ angular distributions have their maximum around 19°, the shapes of the summed curves are not sensitive to the relative amplitudes of the two components. Therefore, the assignments and spectroscopic factors for the unresolved states should

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

† Present address: School of Physics, University of Minnesota, Minneapolis, Minn. 55455.

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

Particle	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
			1.2	0.65				$\lambda=25$	1.4

not be taken too seriously. However, both for $Q=0.54$ MeV and for $Q=-0.32$ MeV the angular distribution shows clear evidence of an $l=2$ component. Two $\frac{7}{2}^+$ states (at 0.726 and 0.757 MeV) in Nb^{95} are known from the study of the β decay[9] of Zr^{95}. On the other hand, the 0.77-MeV state observed in the $Mo^{96}(d, He^3)Nb^{95}$ reaction[3] is most likely $\frac{3}{2}^-$, and therefore should not be strongly excited in the (He^3, d) reaction. From these considerations the angular distribution to the 0.77-MeV state was tentatively assumed to be doublet consisting of $l=2$ and $l=4$ components. In the case of the 1.63-MeV state, the separation was more arbitrary.

The results of the present experiment are summarized in Table II and are compared with the previous data in Fig. 3. A shell-model calculation by Vervier[5] predicts that there are $\frac{13}{2}^+$, $\frac{5}{2}^+$, $\frac{7}{2}^+$, and $\frac{11}{2}^+$ states around 0.9 MeV, none of which should be excited by the (He^3, d) reaction according to the assumption of a Sr^{88} core. It is not surprising that some of them, especially the $\frac{5}{2}^+$ and $\frac{7}{2}^+$ states, contain some single-particle components and are excited by the (He^3, d) reaction. The calculations also shows that there is a $\frac{9}{2}^+$ state at about 1.2 MeV. A state observed at 1.27 MeV in the present experiment may correspond to the predicted $\frac{9}{2}^+$ state.

The $l=2$ strength, which belongs to the next major shell, seems to be distributed among many states. The strongest $l=2$ transition was observed at 2.16 MeV in Nb^{95}, but it carries only a fraction of the total strength.

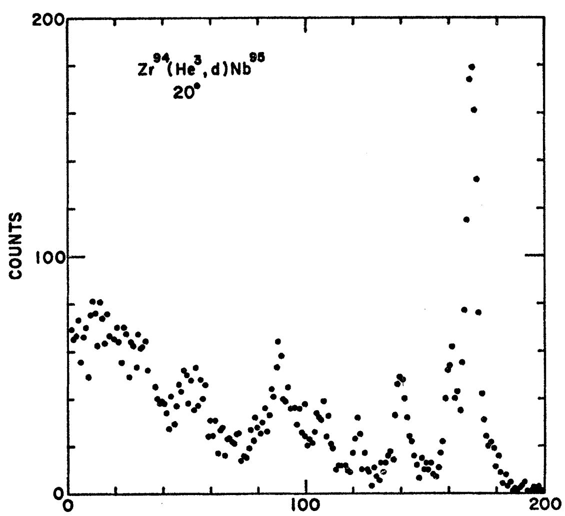

FIG. 1. Typical deuteron spectrum from the $Zr^{94}(He^3, d)Nb^{95}$ reaction at $\theta_{lab}=20°$.

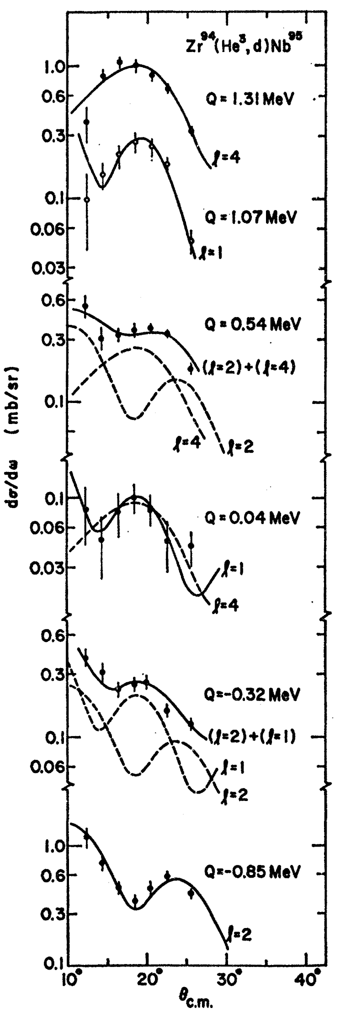

FIG. 2. Angular distributions for the $Zr^{94}(He^3, d)Nb^{95}$ reaction. Solid and dashed curves are DWBA calculations. For unresolved states, solid lines show the sums of two dashed lines.

[9] *Nuclear Data Sheets*, compiled by K. Way *et al.* (U.S. Government Printing Office, National Academy of Sciences—National Research Council, Washington 25, D.C., 1960), NRC 60-5-119; 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).

TABLE II. Summary of the results of the present $Zr^{94}(He^3, d)Nb^{95}$ experiment.

(MeV)	E_{exc} (MeV)	l	j^π	C^2S
1.31	0	4	$\frac{9}{2}^+$	0.78
1.07	0.24	1	$\frac{1}{2}^-$	0.27
0.54	0.77	(4) 2	$(\frac{7}{2}^+)$ $(\frac{5}{2}^+)$	0.22 0.05
0.04	1.27	(1) (4)	$(\frac{1}{2}^-)$ $(\frac{9}{2}^+)$	0.08 0.06
−0.32	1.63	(1) 2	$(\frac{1}{2}^-)$ $(\frac{5}{2}^+)$	0.16 0.03
−0.85	2.16	2	$(\frac{5}{2}^+)$	0.15

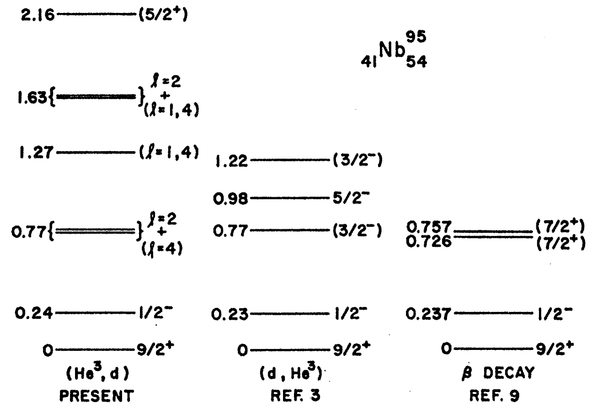

FIG. 3. Energy-level schemes of $_{41}Nb_{54}^{95}$ as deduced from (He^3, d), (d, He^3), and β-decay experiments.

This may be understood from the presence of four extra neutrons outside the $N=50$ core and the $\sim$5-MeV separation[10] between the $g_{9/2}$ and $d_{5/2}$ single-particle orbits.

It may be interesting to compare the spectroscopic factors of the ground state and the first excited state obtained here with the spectroscopic factors from the other experiments. For that purpose the wave functions assumed were:

Zr^{94} (ground state)

$$a(p_{1/2}{}^2)_0+b(g_{9/2}{}^2)_0,$$

Nb^{95} (ground state)

$$c(g_{9/2}{}^3)_{v=1,9/2}+d[g_{9/2}(p_{1/2}{}^2)_0]_{9/2},$$

(first-excited state)

$$[(g_{9/2}{}^2)_0 p_{1/2}]_{1/2},$$

Mo^{96} (ground state)

$$e[(p_{1/2}{}^2)_0(g_{9/2}{}^2)_0]_0+f(g_{9/2}{}^4)_{v=0,0}.$$

Wave functions of this kind are probably inadequate to describe the higher states, but they might be reasonably good for the ground state and the first excited state. From the study of the $Zr^{94}(d, He^3)Y^{93}$ reaction, Preedom *et al.*[2] obtained the values $a^2=0.66$ and $b^2=0.34$. From our (He^3, d) spectroscopic factor of the first excited state of Nb^{95}, one obtains $b^2=0.27$ and accordingly $a^2=0.73$. These are in good agreement with the results of Preedom *et al.*, considering the large ambiguities in the extraction of the spectroscopic factors. Therefore, one can safely assume that $a^2\approx0.7$ and $b^2\approx0.3$. The spectroscopic factors previously obtained[3] for the $Mo^{96}(d, He^3)Nb^{95}$ reaction are $C^2S(\text{g.s.})=2.9$ and $C^2S(\text{1st e.s.})=1.6$. If we normalize these values to the sum-rule limit, we obtain $C^2S(\text{g.s.})\approx2.6$ and $C^2S(\text{1st e.s.})\approx1.4$. The latter gives $e^2\approx0.7$ and therefore $f^2\approx0.3$. From these values and $C^2S(\text{g.s.})\approx2.6$, one obtains two sets of values: $c^2=0.36$, $d^2=0.64$ and $c^2=0.58$, $d^2=0.42$. For the present case of the $Zr^{94}(He^3, d)$ reaction, the first set gives $C^2S(\text{g.s.})=0.92$ or 0.14 and the second set 0.85 or 0.03, depending on the phase factors. Although our experimental value 0.78 favors the second set, both sets give reasonable agreement within the errors. Spectroscopic factors for the $Mo^{96}(d, He^3)Nb^{95}$ and $Zr^{94}(He^3, d)Nb^{95}$ reactions have about 15% errors, without including the ambiguity in the DWBA calculations. The shell-model calculations[4,5] indicate $d^2\approx0.6$–0.7 for Nb isotopes and thus favor the first set. Study of the (He^3, d) reaction on the other Zr isotopes and on Mo isotopes, combined with the results of the (d, He^3) reaction on these nuclei, will give more systematic information on the wave functions.

ACKNOWLEDGMENTS

The authors are indebted to Dr. R. M. Drisko for a copy of the code JULIE used in the distorted-wave calculation. The target was prepared by F. J. Karasek. The technical assistance of J. Bicek and the cooperation of the cyclotron group is gratefully acknowledged.

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