tration analysis is improved, such considerations will be warranted.

[17]This value is comparable with that obtained in Ref. 3.

[18]We have utilized residual resistivity, neutron activation, and optical absorption to aid in the C_d analysis. Care has been exercised to reduce the possibility of Mn oxidation. D. H. Howling, Phys. Rev. 155, 642 (1967). However, the most serious current experimental problem is the determination of the "effective" Mn concentration in the low-ppm range.

EXPERIMENTAL STUDY OF THE $(He^3, d\tilde{p})$ REACTION*

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The (He^3, d) stripping reaction, which is similar to the (d,n) reaction, is now extensively used because of the advantage in observing an outgoing charged particle. The (He^3, d) reaction at medium energy is known to be direct and to strongly excite isobaric analog states. These states, when proton-unstable, have recently been investigated by the observation of their decay protons.[1] This method has also been used for the study of the (d,n) reaction.[2] It is natural to expect that the advantages of the (He^3, d) reaction and the proton-decay method can be combined in studying the following sequential reaction:

$$Z^A + He^3 \to (Z+1)^{A+1} + d; \quad (Z+1)^{A+1} \to Z^A + \tilde{p},$$

where the notation $\tilde{p}$ emphasizes the fact that the proton results from the decay of the intermediate-product nucleus. Information on the excitation of the intermediate nucleus $(Z+1)^{A+1}$ is gotten in the usual way by observing the deuteron spectrum, while decay properties of the intermediate states, as well as properties of states of the final nucleus, can be studied by observing the spectrum of coincidences between the deuterons and the decay protons. We present here the results of an experimental study of such a sequential reaction on Zr^{90}. Data based on brief $(He^3, d\tilde{p})$ experiments on Zr^{91} and Zr^{92}, as well as C^{12} and O^{16}, will also be discussed.

The zirconium targets were self-supported and isotopically enriched, while Mylar was used for the study of C^{12} and O^{16}. An 18.7-MeV He^3 beam was used in the experiments, with beam currents limited to about 40 nA to prevent excessive counting rates due to elastic scattering. 55- and 1000-μ silicon detectors were used in two E-ΔE mass-discrimination systems for the detection of coincident protons and deuterons. The proton telescope included a third detector to discriminate against transmitted particles. Both systems were adjusted to have identical gain. The data were displayed on a 64×64-channel analyzer with a channel width of 182 keV. The energy stability was better than $\pm0.5\,\%$ per day. Scattering angles were selected at 90° and 270° for protons and deuterons, respectively, and each solid angle was 5.5×10^{-3} sr. Observed counting rates were 60 counts per hour, with accidentals accounting for less than 5 % of the total counts. The $Zr^{90}(He^3, d\tilde{p})Zr^{90}$ data were accumulated for 33 h. Channels were sometimes added in order to get statistically meaningful results.

The energy dependence of the Nb^{91} excitation in the one-step reaction $Zr^{90}(He^3, d)Nb^{91}$ is shown in Fig. 1(a). A similar structure is seen in Fig. 1(b), which displays deuterons in coincidence with decay protons and is free from contribution from C^{12} and O^{16} contaminants. The cutoff at the lower energy side of Fig. 1(b) is apparently due to the opening of neutron channels, while the cutoff at the higher energy side is due to the coincidence requirement on the protons. The cutoff at the neutron threshold suggests that the direct break-up of He^3 into a deuteron and a proton is very small and that the proton width is much smaller than the neutron width above the neutron threshold, in agreement with a recent $(p, n\tilde{p})$ study.[3] Similar conclusions are derived from the observed small magnitude of the $(He^3, d\tilde{p})$ cross section for Zr^{91} and Zr^{92}, for which the isobaric analog states (IAS) of the ground states are already neutron-unstable.

The prominent (starred) peaks of Fig. 1 correspond to the excitation in Nb^{91} of the ground IAS of Zr^{91}, while the structure at lower channels corresponds to excitation of excited IAS.

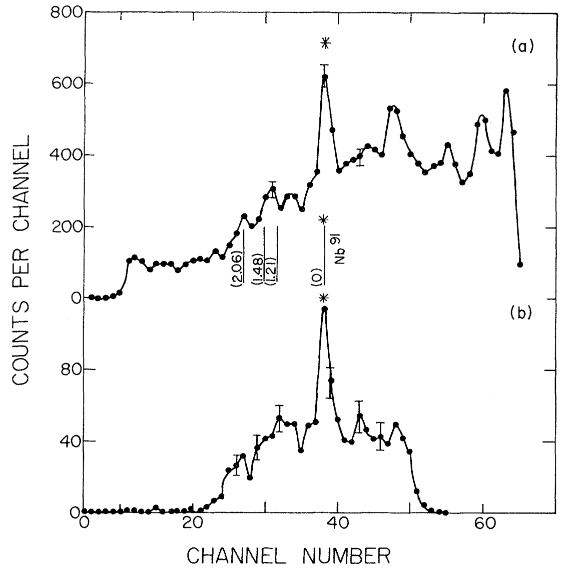

FIG. 1. (a) Deuteron spectrum from $Zr^{90}(He^3,d)Nb^{91}$ at 90°. (b) Coincidence deuteron spectrum from the reaction $Zr^{90}(He^3,d\tilde{p})Zr^{90}$. The prominent (starred) peaks correspond to the ground IAS of Zr^{91}.

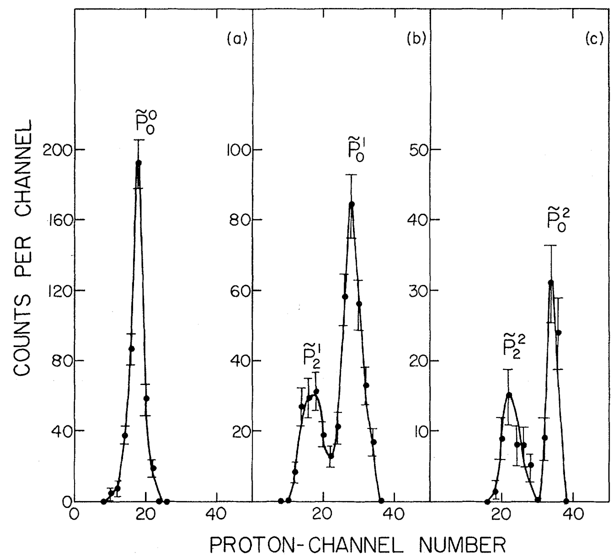

FIG. 2. Spectrum of decay protons from the reaction $Zr^{90}(He^3,d\tilde{p})Zr^{90}$. (a) From the ground IAS. (b) From the region in Nb^{91} corresponding to the IAS of the 1.21-1.48 MeV. (c) From the region in Nb^{91} corresponding to the IAS of 2.06 MeV. The solid line connects the points merely as a guide.

The position of the first broad peak of Fig. 1(b) is consistent with the excitation of the 1.21- and/or 1.48-MeV IAS, and the position of the next peak could be associated with the 2.06-MeV IAS.

Figure 2(a) displays the $\tilde{p}$ spectrum in coincidence with the deuterons of the ground IAS [starred peak of Fig. 1(b)]. As expected, only a $\tilde{p}_0^{\,0}$ proton transition to the ground state of Zr^{90} is observed.[4] The $\tilde{p}$ spectrum from the excited analog region at 1.21-1.48 MeV is displayed in Fig. 2(b). The $\tilde{p}_2^{\,1}$ transitions to the 2.18- and 2.32-MeV states in Zr^{90} are clearly seen as well as the stronger $\tilde{p}_0^{\,1}$ transition to the ground state. There is apparently very little contribution from a $\tilde{p}_1^{\,1}$ transition to the 0^+ first excited state in Zr^{90} at 1.75 MeV. If the 1.21-MeV IAS is connected with the ground state of Zr^{90}, and the 1.48-MeV IAS is connected with the 1.75-MeV state in Zr^{90},[4] our data imply that the 1.48-MeV state was excited only weakly in the (He^3,d) first-step reaction. It might be worth noting that the 1.75-MeV state is excited very weakly in inelastic scattering of He^3.[5] The $\tilde{p}$ spectrum from the excited analog region around 2.06 MeV decays to the ground state, $\tilde{p}_0^{\,2}$, and to the 2.18- and 2.32-MeV unresolved states $\tilde{p}_2^{\,2}$, in Zr^{90} as seen in Fig. 2(c). The 1.75-MeV state of Zr^{90} is again not appreciably populated.

The angular distribution for deuterons corresponding to the ground IAS (not shown) has two maxima, the first at approximately 55° and the second at approximately 125°. The integrated cross section for this reaction is about 5.5 mb.

An apparent structure for the excitation region below the ground IAS in Nb^{91} is seen in Fig. 1. $(He^3,d\tilde{p})$ measurements on Zr^{91} and Zr^{92} gave very low yield, and the Zr^{91} and Zr^{92} contaminants could therefore not account for this structure. Contribution from C^{12} and O^{16} is discounted due to the motion of the center of mass. We conclude that the structure apparently corresponds to the highly excited $T_<$ states in Nb^{91}.

The $Zr^{90}(He^3,d\tilde{p})$ data were further analyzed by plotting the spectrum of E_p+E_d. This spectrum corresponds to states of the final (and target) nucleus Zr^{90} and is shown in Fig. 3, where the ground state and the unresolved states at 2.18-2.32 MeV are clearly seen, with possible weak peaks at 1.75 and 2.745 MeV.

The analysis of the p-d coincidence data for Mylar (not shown here) clearly shows excitation of the 3.86- and 5.6-MeV states in F^{17} as well as the 6.38-MeV state in N^{13}, in agreement with proton elastic scattering.[6] The $(He^3,d\tilde{p})$

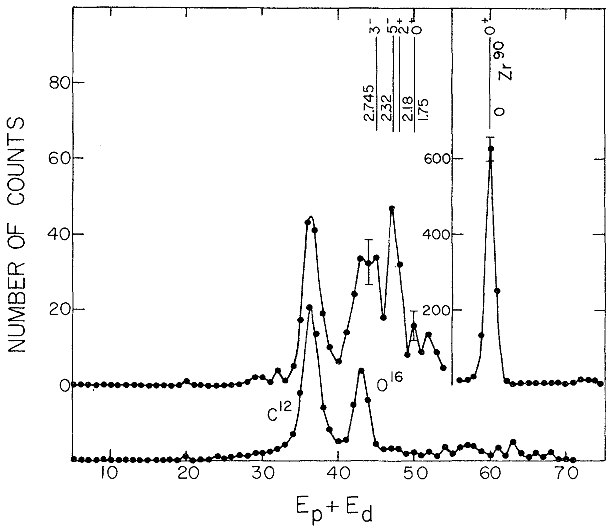

FIG. 3. Population of states of the final (and target) nucleus. The upper curve is for the Zr^{90} target, and the lower curve is for Mylar.

reaction thus appears to be useful for the investigation of proton-unstable regions in light nuclei as well as in medium-A nuclei.

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[2]C. Fred Moore, Charles E. Watson, S. A. A. Zaidi, James J. Kent, and James G. Kulleck, Phys. Rev. Letters 17, 926 (1966).

[3]A. I. Yavin, R. A. Hoffswell, D. Jamnik, and T. M. Noweir (to be published).

[4]C. Fred Moore, S. A. A. Zaidi, and J. J. Kent, Phys. Rev. Letters 18, 345 (1967).

[5]D. E. Rundquist, M. K. Brussel, and A. I. Yavin (to be published).

[6]Nuclear Data Sheets, compiled by K. Way et al. (Printing and Publishing Office, National Academy of Sciences-National Research Council, Washington, D. C., 1962).

USE OF POLARIZED DEUTERONS TO DETERMINE THE TOTAL ANGULAR MOMENTUM TRANSFER IN STRIPPING REACTIONS*

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For more than a decade the deuteron stripping reaction has played an important role in nuclear spectroscopy. From the shape of the differential cross section of the outgoing nucleon at forward angles, it is possible to determine the orbital angular momentum l of the captured nucleon.[1] However, since the captured nucleon has spin, the total angular momentum transfer, j, is not uniquely determined, i.e., $j = l \pm \frac{1}{2}$. If j as well as l could be determined, the spin of the residual nucleus would be determined in those cases where one is dealing with spin-zero target nuclei.

Our method to determine the spin of the residual nucleus is by measurements of the directional correlation of the reaction products in $(n,\gamma\gamma)$ reactions with thermal neutrons or in $(d,p\gamma)$ reactions. Such measurements are usually difficult.[2] Recently, a method to determine j from stripping reactions has been proposed by Lee and Schiffer et al.,[3,4] who observed that for a given l, the shape of the angular distributions in (d,p) reactions shows a systematic dependence on j. However, even the best analyses of stripping reactions have not been successful in reproducing the observed dependences.[4] In addition, since the effects usually appear in regions away from the stripping peak, they may be obscured by compound-nucleus processes.

Measurements of the polarization of the outgoing nucleon in stripping reactions have been suggested as another possible method.[5] Because of experimental difficulties, only a few measurements have been made[6] and thus any comparison with theory becomes difficult and any formulation of empirical rules questionable.[7] Instead of studying the outgoing nucleon polarization,[8] one may investigate the effects on the stripping cross section when polarized deuterons are used to initiate the reaction.[9,10] As the beam intensity from polarized-ion sources improves, this type of experiment becomes much more attractive than a polarization measurement.

We have measured the vector analyzing power, $P_d(\theta)$, for a number of (d,p) reactions for which j and l had been determined previously.[11]