ties smaller than 15° and, if present, would not contribute to the selected group of seven events.

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†Visitor from Physikalisches Institut, Universität Bonn, Bonn, Germany.

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Total Spin Measurement of Proton Hole States by the (t, α) Reaction*

E. R. Flynn, R. A. Hardekopf, J. D. Sherman, and J. W. Sunier
Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545

and

J. P. Coffin†
Centre de Recherches Nucléaires, Strasbourg, France

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It is shown that it is possible to measure the total angular momentum of proton hole states by means of the (t,α) reaction using a recently developed polarized triton source. The reactions ^{90}Zr$(t,\alpha)^{89}$Y and ^{208}Pb$(t,\alpha)^{207}$Tl have been studied at 17-MeV bombarding energies and show large differences in the analyzing powers between spin-orbit partners $p_{1/2}$ and $p_{3/2}$ in the former case and $d_{3/2}$ and $d_{5/2}$ in the latter case. It is concluded that measurement of asymmetries in (t,α) reactions is a powerful technique to assign both l and j transfers for proton-pickup reactions.

The use of polarized beams in nuclear spectroscopic studies has proven to be quite fruitful; for example, the utilization of the (d,p) reaction to assign total spin, j, to neutron levels has been very successful.[1] However, in the study of levels whose principal parentage lies in proton orbitals, the available results are quite scarce. Aside from a brief study of the polarized-deuteron $(d,{}^3\mathrm{He})$ reaction[2] no experimental data exist, this reaction suffering somewhat from a negative Q value (~ −2 to −4 MeV), requiring high bombarding energies to obtain reasonable cross sections. The (t,α) reaction may also be used to study proton hole states and has the interesting features of a very high Q value (~ +12 MeV) and rather simple spin characteristics. This reaction has been used extensively throughout the periodic table and has found particular success in the lead region[3] where the positive Q value makes such studies possible at Van de Graaff accelerator energies. An unfortunate characteristic of the (t,α) reaction has been the rather featureless angular distributions which require precise data at a large number of angles in order to determine the angular momentum transfer l.

It is the purpose of this Letter to show that the use of a polarized triton beam not only permits separation of spin-orbit partners through measurement of the analyzing powers, but that these analyzing powers exhibit more structure than the differential cross sections. This results in both l and j assignment possibilities from the analyzing-power measurements alone. Moreover, the sign and magnitude of these effects are reasonably well reproduced by distorted-wave (DW) techniques, indicating that Q-value corrections for fragmented states can be reasonably accounted for. The examples chosen for study were ^{90}Zr and ^{208}Pb where proton hole spin-orbit partners of $p_{3/2}$-$p_{1/2}$ character exist in the former and $d_{3/2}$-$d_{5/2}$ in the latter.

The experiments were performed using a 17-MeV beam of polarized tritons[4] with an average polarization of 78% and an intensity of 30–50 nA on target. The targets consisted of a rolled ^{90}Zr metallic target of ~500-μg/cm^2 thickness and a ^{208}Pb evaporated target of ~125-μg/cm^2 thickness. The reaction α particles were detected in the focal plane of a quadrupole–triple-dipole spectrometer by a 1-m-long helical proportional counter.[5] The spectrometer was operated at a solid angle of 14.3 msr resulting in exposure times of ~10 min per angle for the ^{90}Zr target. The energy resolution, limited by the target thickness in both cases, was 60 keV for the ^{90}Zr target and 18 keV for the ^{208}Pb target, both being sufficient to resolve the states of interest. Data were taken at eleven angles for the lighter target and at ten angles for the heavier, a range of 10° to 60° being covered in 5° intervals. The analyzing powers were obtained by reversing the polarization of the beam at the source at each angle and using the relation

$$A_y = \frac{N^+ - N^-}{N^+p^- + N^-p^+},$$

where N and p refer to the number of counts and the beam polarization, respectively, and + and − refer to up and down spin.

The analyzing-power results are shown in Figs. 1 and 2 for the ^{90}Zr$(t,\alpha)^{88}$Y and ^{208}Pb$(t,\alpha)^{207}$Tl cases, respectively, together with the differential cross sections obtained by summing N^+ and N^-. All of the cases illustrated represent dominant single-proton-hole levels (i.e., spectroscopic factors $S \geq 0.5$) except for the $g_{9/2}$ state of ^{90}Zr. The figures demonstrate a clear differentiation between spin-orbit partners in both the ^{89}Y and ^{207}Tl final nuclei. In addition, there is substantial structure in the angular distribution of A_y for all four single-proton-hole states in each nucleus. This is in contrast to the rather featureless cross-section angular distributions associated with these reactions,[3] as an examina-

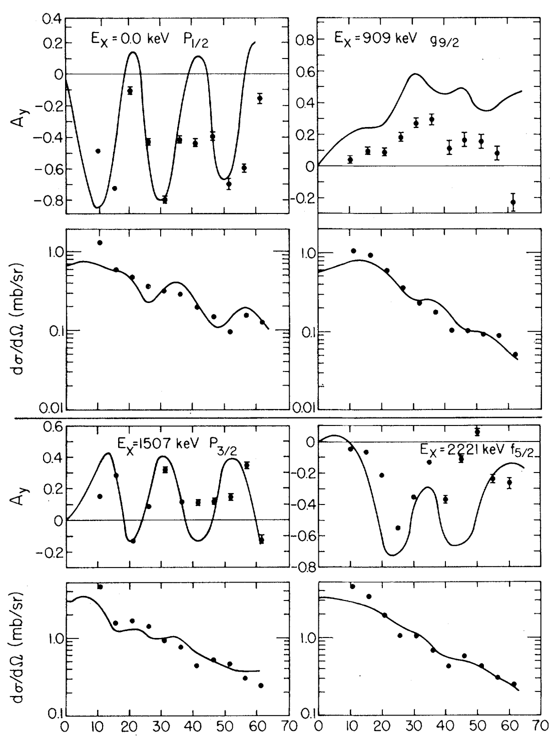

FIG. 1. Differential cross sections and analyzing powers for the four principal proton hole states observed in the reaction ^{90}Zr$(t,\alpha)^{89}$Y. The solid lines are the results of DW calculations.

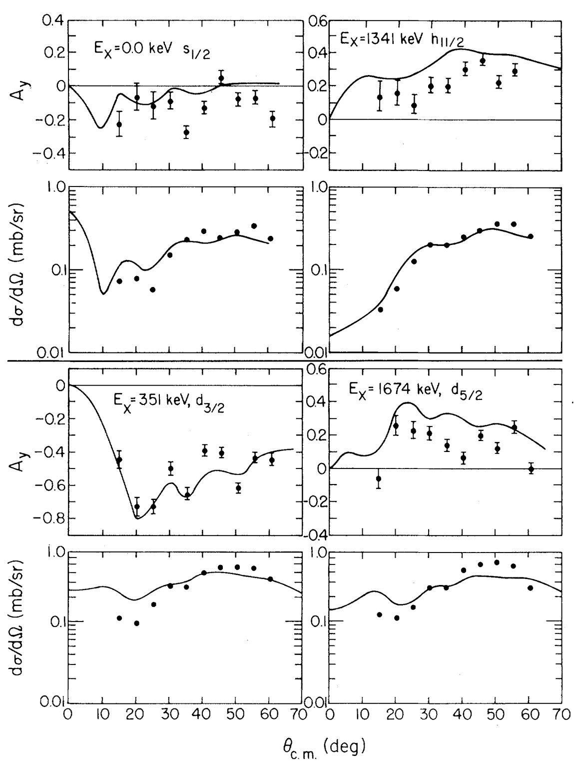

FIG. 2. Differential cross sections and analyzing powers for the four principal proton hole states observed in the reaction ^{208}Pb$(t,\alpha)^{207}$Tl. The solid lines are the results of DW calculations.

tion of the figures indicates, especially in the case of lead. The results shown in Figs. 1 and 2 can then be used as templates in adjacent nuclei to establish both l and j where spins are unknown. The differential cross section serves only to extract spectroscopic strength in these cases.

It is of interest to examine the applicability of DW techniques to the measured A_y's. Such a comparison not only is of use from a reaction-mechanism point of view, but also serves the function of indicating to what extent one may carry out extrapolation of the measured templates of the "pure" single-hole states to fragmented single-particle strength in adjacent nuclei at different Q values. In the case of the (d,p) reaction Q-value effects have been shown to be important for changes of 3–4 MeV although spin-orbit partners could still clearly be established.[1] DW calculations were performed using the code DWUCK,[6] a triton optical potential using the recently measured spin-orbit potential for tritons,[7] and an α potential from the work of McFadden and Satchler.[8] In the case of ^{208}Pb the 15-MeV polarized elastic-scattering results were not distinctive and the parameters of Ref. 7 did not fit the (t,α) data well. Thus for this case, previous triton parameters established at 20 MeV[9] were used with an added spin-orbit term of 6-MeV depth. The DW results are shown in Figs. 1 and 2. The shapes of the data are reasonably well reproduced in view of the large oscillations present in the analyzing power, and the sign and magnitude agree with the observed results. The quality of the analyzing-power fits is in general comparable to the fits to the differential cross sections. Spectroscopic values were obtained by using a normalization value of 23 for the DW calculations.[6] This results in spectroscopic factors for the case of ^{90}Zr of 1.06 and 2.38 for the $p_{3/2}$ and $p_{1/2}$ states, respectively, in agreement with previous (t,α) values[10] of 1.1 and 2.4. For the ^{208}Pb target, values of $S=4.5$ and $S=3.1$ were obtained for the $d_{3/2}$ and $d_{5/2}$ hole states, respectively, as compared to $S=4.6$ and $S=3.7$ from Ref. 3.

The shape and magnitude of the analyzing power were found to be somewhat sensitive to the α optical potential, the greatest uncertainty in the present analysis. However, good fits to all of the single-hole states do not occur simultaneously for any α potential. The parameters of Ref. 8 produced the best fit to the spin-orbit partners. The Q-value dependence is found to be small in the cases examined because of the large positive Q values associated with these reactions. Thus the general agreement of DW results with the data and the lack of large Q-value corrections indicate that the experimental signatures obtained from states of known spin may be used over a relatively wide band of excitation and energy. This have been further verified by a study of the reaction $^{206}\mathrm{Pb}(t,\alpha)^{205}\mathrm{Tl}$, at four angles, to three $\frac{3}{2}^{+}$ states at 0.204, 1.141, and 1.341 MeV, respectively.[11] All of these states gave the same values of A_y as in the $^{207}\mathrm{Tl}$ $d_{3/2}$ case.

The technique used here to assign total spin values to proton hole states is thus seen to be of significant value in direct-reaction nuclear spectroscopy. The (t,α) reaction has proven to be a very successful tool in this field and the additional information available from measurement of the analyzing power should increase this capability by firmly establishing spin values.

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†Visiting staff member at Los Alamos Scientific Laboratory.

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