PHYSICAL REVIEW C VOLUME 37, NUMBER 3 MARCH 1988

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Analyzing powers for the reaction $^{2}H(\vec{p},\gamma)^{3}He$ at 800 MeV

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(Received 10 December 1987)

Analyzing powers have been measured for the reaction $^{2}H(\vec{p},\gamma)^{3}He$ at a proton beam energy of 800 MeV. The results are in good agreement with microscopic calculations. At this energy the data are most sensitive to the meson-exchange amplitudes. Proton initial-state interactions also play an important role.

Radiative proton capture is one of the most fundamental processes in nuclear physics. The interaction between a real photon and the charge and magnetization densities in the nucleus are well understood and this fact has been exploited in the study of $(\gamma,\vec{p})$ and $(\vec{p},\gamma)$ reactions at low energies. At low energies the reaction is primarily sensitive to the location and strength of the isovector giant resonances. However, the reaction mechanism is not as well determined at photon energies greater than about 100 meV. At these energies, the Born amplitudes, which are produced by the one-body operators, predict (γ,p) cross sections for heavy nuclei ($A>3$) which are generally too small at large angles.[1,2] This is a consequence of the large values of three-momentum transfer, q, that are encountered for the exclusive reactions. In the present measurement, q ranges from 600 to 1200 MeV/c. The traditional approach to this problem has been to include two-body amplitudes of the meson-exchange type,[3] including virtual excitation of the $\Delta(1232)$ resonance.[4] These attempts have met with rather limited success. This is partly due to the severe approximations that must be used to calculate the two-body amplitudes in heavy nuclei. For example, current conservation is often invoked to represent the electric meson-exchange currents in terms of the nuclear density.[3] Three-body systems offer two advantages in this respect: two-body amplitudes can be calculated explicitly, and the bound-state wave functions are well determined. Also, the measurements are easier because the light nuclear recoil particles can be detected.

While the differential cross sections for photoproton and proton capture reactions have been extensively studied at intermediate energies,[1,5,6] the same cannot be said of the polarization observables. Only four intermediate-energy polarization measurements on targets heavier than deuterium have been reported in the literature. The photon asymmetry for the reaction $^{3}He(\vec{\gamma},p)^{2}H$ has been measured at photon energies from 90 to 350 MeV,[7] and extensive data exist for the analyzing powers in the reaction $^{2}H(\vec{p},\gamma)^{3}He$ at 200, 350, and 500 MeV, with sparse data measured at 450 MeV as well.[5] Proton polarization was also measured at one angle in the photodisintegration measurements on ^{3}He using linearly polarized photons.[8]

Polarization measurements are essential if one is to test the details of the reaction mechanism at intermediate energies. This is apparent from analyses of the elementary deuteron photodisintegration reaction.[9,10]

In the present experiment, analyzing powers have been measured for the reaction $^2\mathrm{H}(\vec{p},\gamma)^3\mathrm{He}$ at a proton laboratory kinetic energy of 800 MeV. This beam energy corresponds to a total center-of-mass kinetic energy of 490 MeV, well above the 300-MeV excitation energy of the $\Delta(1232)$ resonance. Data were obtained at photon center-of-mass scattering angles spanning the range from 45 to 139°.

The experiment was carried out at the Clinton P. Anderson Meson Physics Facility (LAMPF). A proton beam typically 80% polarized impinged on one of two liquid deuterium targets located in an evacuated target chamber. The targets were flat disks with thicknesses of 0.5 and 1.0 cm in the direction of the beam. The beam intensity, typically 5 nA, was continuously monitored with two gas proportional chambers located down stream of the target. The beam polarization was also continuously monitored, by measuring the asymmetry of $\vec{p}p$ scattering from the hydrogen in a thin Mylar target located several meters upstream from the target.

Recoiling ^{3}He nuclei from the reaction $^2\mathrm{H}(\vec{p},\gamma)^3\mathrm{He}$ were magnetically analyzed in the High Resolution Spectrometer (HRS). Particle identification for each event was achieved by means of scintillator pulse height and time-of-flight measurements near the focal plane of the HRS. Position measurements in the focal plane drift chambers determined the momentum and scattering angles of the recoils, and this information was used to calculate the missing mass for each event. Since a bound ^{3}He nucleus was always identified in the final state only π^0 and gamma peaks were produced in the final missing-mass spectra (see Fig. 1).

Gamma rays in coincidence with ^{3}He particles were detected at the angles appropriate for the $(\vec{p},\gamma)$ reaction. The primary function of this coincidence was to reduce the rate of background ^{3}He events from inclusive reactions on the Mylar target walls. Some reduction in the π^0 rate was also observed since occasionally both pion decay gammas missed the gamma detectors. The gamma detector was comprised of a 1.3 cm Pb converter followed by two Pb-glass (SF5) Čerenkov detectors (each 2 cm thick) operated in coincidence. The overall efficiency of the gamma arm was about 80%.

Missing-mass spectra for each beam polarization were fitted with Gaussian peak shapes for the pion and gamma peaks. A uniform background was also included to represent the contribution from the target windows. Data from adjacent momentum bites in the HRS show nearly uniform background. A chi-squared minimization was performed to determine the areas of the gamma peaks in the spectra. Analyzing powers were extracted for the gamma peak and the results are depicted in Fig. 2. The uncertainties assigned to the data primarily reflect the statistical uncertainties from the peak fits, except at the smallest angles. Also, the change in the results was determined when a Breit-Wigner peak shape was used in the fits rather than a Gaussian. The resulting chi-squared values increased somewhat. This procedure was done in order to estimate the sensitivity of the results to the (poorly determined) tail of the pion peak. The change in the analyzing power was added in quadrature with the standard deviation from the Gaussian fits to yield the uncertainties shown in Fig. 2. At 45° and 65° this contribution dominates because the gamma peak and pion peak are poorly resolved. The low ^{3}He energies at these angles produce higher energy loss and more Coulomb multiple scattering in the target, thus degrading the resolution. Not included in the figure is the systematic uncertainty due to the beam polarization measurement. This contribution is estimated to be about ±3%.

As is evident from Fig. 2 the present analyzing power

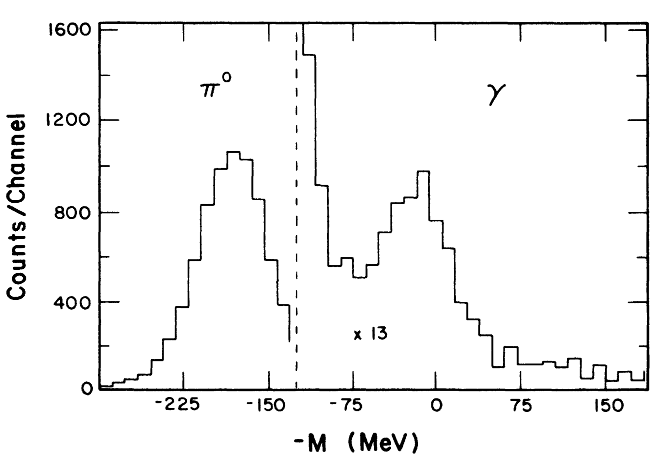

FIG. 1. Missing-mass spectrum taken at ^{3}He laboratory scattering angle equal to 18.6°, corresponding to a photon center-of-mass scattering angle equal to 99.4°. This spectrum is the sum of the proton-polarization up and polarization down spectra. The pion and gamma peaks are indicated.

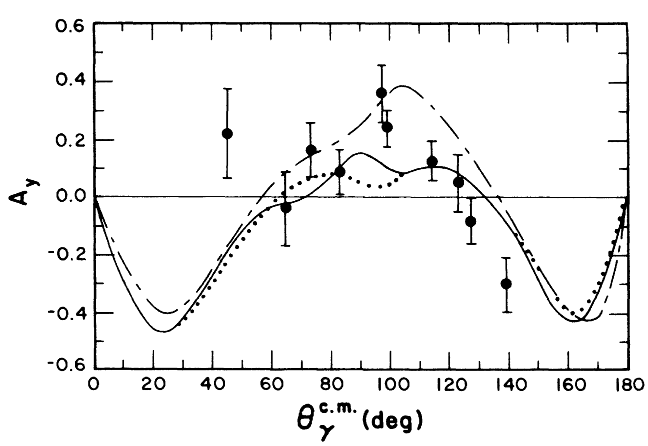

FIG. 2. Proton analyzing powers for the reaction $^2\mathrm{H}(\vec{p},\gamma)^3\mathrm{He}$. The theoretical results include two-body amplitudes. The dot-dash curve used plane waves for the initial state and Faddeev-model wave functions generated with the Paris potential for ^{3}He. The solid curve is the result when proton initial-state interactions are included. The dotted curve also includes initial-state interactions but with ^{3}He wave functions generated with the Reid potential.

data show some structure. A maximum value of 0.36 ± 0.10 was measured at 97°, and the data show a monotonic decrease to a value of -0.31 ± 0.09 at 139°. These values are of interest because the Born terms in a theoretical description of this reaction produce negligible contributions to the analyzing powers when plane waves are used for the initial proton wave functions.[11] When two-body amplitudes and proton initial-state interactions are included, the theoretical results are in good agreement with the analyzing powers measured at 200 and 350 MeV.[5] Proton initial-state interactions produce most of the effect at those energies. At higher energies the theory is most sensitive to the two-body currents. Unfortunately, the predicted analyzing powers are not in good accord with the 500-MeV data.[5] In that case the most serious discrepancies existed at angles forward of 70°, but the theoretical results fell well below the data at large angles also. The present 800-MeV data do not address the small-angle region very well; however, at large angles we observe a more steeply falling distribution than was measured at the lower energy, which leads us to a different conclusion regarding the theoretical model.

At 800 MeV the plane-wave predictions which include two-body currents are already close to the data. These results are plotted as the dot-dash curve in Fig. 2. The diagrams that are included in this calculation are depicted in Fig. 3. This prediction is altered relatively little when proton initial-state interactions are included in the Born amplitudes. These results, which are depicted as the solid and dotted curves in Fig. 2, are in good agreement with the data. It is important to note that in the present analysis (including initial-state interactions) the Born terms alone, without meson-exchange or delta currents, make very small contributions to the analyzing power except at angles close to 90°, where A approaches the value -0.1. Thus, while initial state interactions play an important role at 800 MeV, they are not the dominant process. This indicates that the high-energy data are sensitive to the details of the two-body amplitudes. For example, calculations with some of the amplitudes set to zero show that the delta currents and the other meson-exchange currents contribute roughly in equal measure to the predictions in the angular range from 90° to 150°, and both are important to the comparison with the present data.

Since the measured excitation functions[2,6] for exclusive (γ,p) reactions on heavy nuclei do not exhibit the broad $\Delta(1232)$ peak that is evident in deuteron photodisintegration,[12] the role of the delta currents is less apparent for

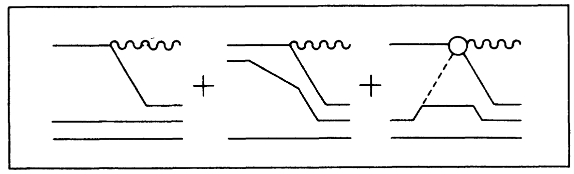

FIG. 3. One-body and two-body reaction diagrams included in the present analysis.

these reactions. However, the inclusion of delta currents as well as other meson-exchange currents in the present analysis was essential in order to obtain nonzero values of A_y and to reproduce the data in Fig. 2.

The present analysis is an outgrowth of theoretical work on the elementary $^2H(\gamma,\vec{p})$ n reaction.[10] A diagrammatic expansion of the one- and two-body amplitudes enables one to include explicitly the meson-exchange and virtual $\Delta(1232)$ contributions. Faddeev model wave functions generated with the Paris potential[13] were used for the ground state of ^3He. As shown in Fig. 2, the results are not very sensitive to the choice of NN potentials; rather modest changes are observed in the theoretical results when the Reid potential[14] is used. Further details of the calculation can be found in Ref. 11.

In view of the fact that the theoretical predictions at small angles are in disagreement with the 500-MeV data in Ref. 5, it would be useful to extend the 800-MeV data to smaller angles as well. This is a particularly interesting region from a theoretical point of view because the analyzing power predictions are almost completely determined by the two-body amplitudes, independent of assumptions about the proton initial-state interactions. For example, calculations carried out with the delta amplitudes set to zero show that the deep minimum predicted at about 25° (see Fig. 2) arises primarily from the delta currents.

In summary, the present data show strong sensitivity to two-body amplitudes in the exclusive $(\vec{p},\gamma)$ reaction. The data agree well with the conventional meson-exchange picture of the reaction, despite the extremely large values of momentum transfer encountered.

The assistance of D. Tedeschi during the data reduction phase of the experiment is gratefully acknowledged. This work was supported in part by the National Science Foundation, the Department of Energy, and the Swedish Natural Science Research Council.

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