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Polarization Transfer in the Reaction T $(p,n)^3$He at 0° for E_p in the Range 3 to 16 MeV*

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The polarization of the neutrons has been measured for the reaction $T(p,n)^3$He at 0° for conditions where the incident beam is transversely polarized. The neutrons were observed to be highly polarized in the same direction as the incident proton spin, with values of the polarization transfer coefficient $K_y^{\,y}(0°)$ ranging from +0.39 to +0.83. R-matrix calculations using published ^{4}He level parameters of Werntz and Meyerhof do not agree well with our measurements.

In this Letter we report the first results for a triple-scattering-type observable in the reaction $T(p,n)^3$He, namely, the polarization transfer parameter at 0°. This experiment demonstrates a large transfer of polarization from the incident proton to the outgoing neutron in the process. The data also allow an important comparison to be made with the analysis of Werntz and Meyerhof[1] on the states of ^{4}He.

The reaction was initiated with a transversely polarized proton beam and the transverse polarization of the outgoing neutrons was measured by a second scattering from helium. In this way, the polarization transfer coefficient[2] $K_y^{\,y}(0°)$ was determined. The coefficient is defined for any angle θ in terms of the M matrix by

$$K_y^{\,y}(\theta) = [\mathrm{Tr}(M\sigma_y^{\,p}M^\dagger\sigma_y^{\,n})]/[\mathrm{Tr}(MM^\dagger)], \qquad (1)$$

where σ_y is the usual Pauli spin matrix for the nucleons. A right-handed coordinate system with the $+y$ axis parallel to $\vec{k}_{in}\times\vec{k}_{out}$ has been assumed. At 0°, the y axis is undefined and was taken to lie in the horizontal plane and to be normal to $\vec{k}_{in}$. In this reaction, $K_y^{\,y}(\theta)$ is similar to Wolfenstein's[3] parameter $D(\theta)$ for nucleon-nucleon scattering, except that the outgoing particle is different from the incoming particle. At $\theta = 0°$, $K_y^{\,y}(\theta)$ depends only upon triplet-triplet and singlet-singlet channel spin transitions. For this case, Eq. (1) may be expressed as

$$K_y^{\,y}(0°) = \frac{2\,\mathrm{Re}[M_{11}^*(M_{00}+M_{ss})]}{2|M_{11}|^2+|M_{00}|^2+|M_{ss}|^2}, \qquad (2)$$

where the singlet (M_{ss}) and triplet (M_{11}, M_{00}) M-matrix elements have the form given by MacGregor, Moravscik, and Stapp[4] for n-p scattering. Thus $K_y^{\,y}(0°)$ is sensitive to few elements of the scattering matrix and as such will provide new information on the four-body system.

Experimentally, a beam of polarized protons produced by the Los Alamos Scientific Laboratory Lamb-shift polarized ion source[5] was accelerated by the model FN tandem accelerator and directed onto a tritium gas target at a pressure of 4.8 atm (absolute). The proton spin polarization vector was oriented parallel to the y axis in the horizontal plane normal to $\vec{k}_{in}$. The y component of the neutron polarization at 0° was measured by scattering the neutrons from a helium polarimeter. Briefly, this polarimeter consisted of a 4.8-mole liquid-helium scintillator operated in fast coincidence with two NE-102 neutron detectors located at scattering angles $\theta_2(\mathrm{lab}) = 115°$ above and below the helium scintillator. The experimental details and data-taking procedures are the same as those discussed by Mutchler, Broste, and Simmons,[6] except that $R_1 = 99$ cm and $R_2 = R_3 = 30$ cm, and the gold beam-stop target assembly was used. The asymmetry e, measured by reversing the proton spin orientation at the ion source, is related to the neutron polarization p_n by the expression $e = p_n P_{n\text{-}\alpha}$. A reversal of the proton spin produces a reversal of the neutron spin according to Eq. (3) below. $P_{n\text{-}\alpha}$, which is the n-α analyzing power calculated from the phase shifts of Satchler *et al.*[7] and averaged over the finite geometry of the detector system, had values ranging from 0.82 to 0.95. The measured asymmetries were increased by multiplicative factors f and g related to background corrections and multiple-scattering corrections, respectively. The quantity f was near unity with values of 1.025 typically. The multiple scattering in the liquid helium led to corrections that were fairly large at low energies, namely, $g = 1.25$ at $E_p = 3$ MeV and $g = 1.13$ at $E_p = 4$ MeV; the corrections were smaller at higher energy, namely, $1.02 \leq g \leq 1.07$ for $E_p \geq 5$ MeV. The uncertainties in these corrections were assumed to be $\frac{1}{3}$ of the correction.

At 0°, the polarization transfer coefficient $K_y{}^y(0°)$ is related to the polarization of the proton beam, p_p, and to the outgoing neutron polarization by

$$p_n(0°) = p_p K_y{}^y(0°). \tag{3}$$

This formula obtains by reference to the formalism of Wolfenstein.[3] The polarization of the beam was measured by an atomic-beam technique[8] to ± 0.01 and was typically 0.90. The intensity of the beam on target varied from 2 to 35 nA, depending upon the transmission through the tandem.

The experimental values of $K_y{}^y(0°)$ are plotted in Fig. 1 as a function of the mean proton energy. Also shown are two theoretical curves that are discussed below. The dominant uncertainty in the coefficients arises from statistical considerations, but also includes uncertainties in the beam polarization and in the multiple-scattering and background corrections. As in the earlier polarization transfer measurements in the reaction[9] $T(d,n)^4$He and the reaction[10] $D(d,n)^3$He, the values of $K_y{}^y(0°)$ are sizable over the whole energy interval, ranging here in magnitude from +0.39 to +0.83. These values are appreciably greater than those reported by Robertson *et al.*[11] in their (p,n) transfer polarization measurements at 0° for D_2, ^{6}Li, and ^{7}Li targets at 30 and 50 MeV, where their largest value reported was −0.23. Polarization transfer parameters were also measured by the Rochester group near 200 MeV for quasielastic scattering in the reaction $D(p,n)2p$. In their D geometry,[12] the magnitude of the measured parameter was always small (≤ 0.087) in the 15°–25° angular interval but was 0.269 at $\theta = 0°$ as determined from their earlier R-geometry measurement.[13] In the latter geometry, however, the parameter was large at $\theta = 10°$.

Werntz and Meyerhof[1] (denoted hereafter by WM) have made an R-matrix analysis of cross-section and polarization data in the reaction $T(p,n)^3$He to determine the level structure of ^{4}He. Their analysis resulted in two solutions, denoted by WM I and WM II, which are frequently used as the "experimental" level structure of ^{4}He. These solutions are characterized by a common $T=0$ spectrum together with $T=1$ spectra which differ chiefly in the ordering of the $J^\pi = 1^-$ levels. Various experimental and theoretical workers have published results favoring solutions similar to WM I[14,15] or to WM II.[16,17]

R-matrix calculations[18] were made for the quantity $K_y{}^y(0°)$ using the WM I and WM II solutions and these are compared with the experimental data in Fig. 1. The calculation procedures differ slightly from WM in treating threshold effects more accurately, but this does not significantly affect the results. In the figure, it is seen that neither curve accurately fits the data. The predictions of both solutions vary too rapidly with energy and are too small in magnitude at the high-

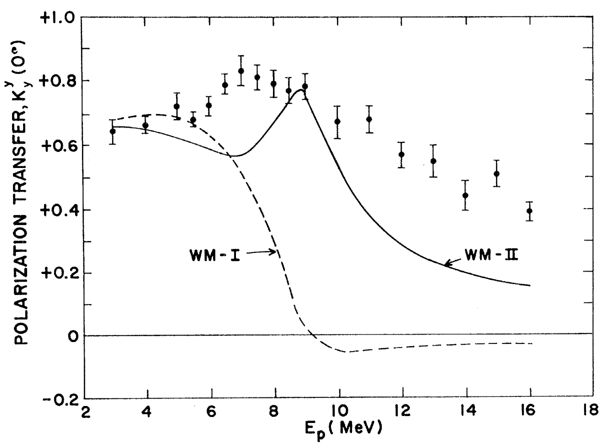

FIG. 1. Experimental values of the polarization transfer coefficient $K_y{}^y(0°)$ are plotted as a function of the mean proton energy. R-matrix calculations using the two solutions of ^{4}He level parameters of Werntz and Meyerhof are compared with the data. The proton energy range covered in the figure corresponds to ^{4}He excitation energies between 21.3 and 33.3 MeV.

er energies. The anomalously rapid energy dependence comes from the positive-parity $T=0$ states. One of these levels ($J^\pi=2^+$, $T=0$) was already considered dubious by WM. Also the reduced magnitudes of $K_y^{\,y}(0°)$ at the higher energies may result from incorrect positions of these $T=0$ levels, but probably suggest that the positive-parity R matrices require contributions from background levels and scattering states other than singlet, which were the only ones that WM included.

The obvious fact that WM II gives a better qualitative description of the data than does WM I requires comment. Our calculations show that the energy dependence of the predictions calculated from Eq. (2) is dominated by the relative *phase* of M_{11} and $M_{00}+M_{ss}$. [For instance, WM I predicts $K_y^{\,y}(0°)=0$ at ≈ 9 MeV because the relative phase is $\pi/2$.] As a result, the shapes of the curves turn out to be especially sensitive to the relative positions and widths of the $T=0$ and $T=1$ levels. Indeed, the uncertainty in the level parameters ($T=0$ in particular) could cause variations in the calculated values at least as large as the observed difference between the predictions of WM I and WM II. Therefore, we feel that the difference between the predictions of this observable for the two solutions is not significant.

Thus it appears that this new observable, which the WM ^{4}He level parameters do not describe very well, may provide a sensitive test of the relations of $T=0$ and $T=1$ levels in the $A=4$ system. We feel that a reliable determination of the level structure of ^{4}He will only come from a comprehensive multichannel analysis of the four-body system. Such an analysis using the same charge-independent R-matrix approach that WM used is currently under way at this laboratory.

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