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The j-dependence of Far-side Dominated (d,p) Reactions

E.J. Stephenson, V.R. Cupps, J.D. Brown, C.C. Foster, W.P. Jones, D.W. Miller, H. Nann, P. Schwandt, J.W. Seubert†, and J.A. Tostevin††

Indiana University Cyclotron Facility, Bloomington, IN 47405 U.S.A.
† Indiana University-Purdue University at Indianapolis
Indianapolis, Indiana 46202 U.S.A.
†† University of Surrey, Guildford, Surrey GU2 5XH U.K.

Recently completed measurements of the vector (A_y) and tensor (A_{yy}) analyzing power for the $^{116}Sn(d,p)^{117}Sn$ reaction[1] (at 79-MeV deuteron energy) include two transitions (ℓ=4 and 5) whose large angle amplitudes appear to originate from the far side of the nucleus.[2] At large angles the interference oscillations are damped, and the analyzing powers follow smooth trends, as shown in Fig. 1. For these large values of ℓ-transfer, there is little dependence of the angular distributions on ℓ. Thus we will use the $7/2^+$ state (0.71 MeV) as an example of a $j=\ell-1/2$ transition and the $11/2^-$ state (0.32 MeV) as an example of a $j=\ell+1/2$ transition to illustrate the j-dependence. For the case where $j=\ell+1/2$, both A_y and A_{yy} rise to large positive values. When $j=\ell-1/2$, both A_y and A_{yy} are predominately negative. The calculations shown here use the DWBA formalism, which has been extended to include an adiabatic prescription for the deuteron scattering wavefunction, consistent optical potential geometries between entrance and exit channels, and finite range deuteron S- and D-states.

The predominant sign of the A_y angular distributions is consistent with angular momentum matching on the far side of the nucleus. In the absence of spin-orbit forces, a spin up deuteron passing on the far side will tend to deposit the neutron into an orbit with ℓ parallel to the deuteron spin. If the stripping originates predominantly from the deuteron S-state and there is negligible spin flip, then both the neutron and proton will have spin up also. The fact that the neutron spin and angular momentum are parallel implies that this deuteron spin state couples well to $j=\ell+1/2$ transitions. Likewise, spin down deuterons couple to $j=\ell-1/2$ transitions. Deuterons with the m=0 spin projection (relative to the normal to the scattering plane) couple only half the time to each kind of state. In the absence of spin-orbit forces (well confirmed by DWBA calculations) and at large angles, A_y will tend toward $-2/3$ when $j=\ell-1/2$ and $2\ell/3(\ell+1)$ when $j=\ell+1/2$ (see Ref. 3). Following a similar argument, it can be shown that A_{yy} will tend toward zero for both types of transition. It is the large angle dependence of A_{yy} on j-transfer that is the new feature of these (d,p) reactions.

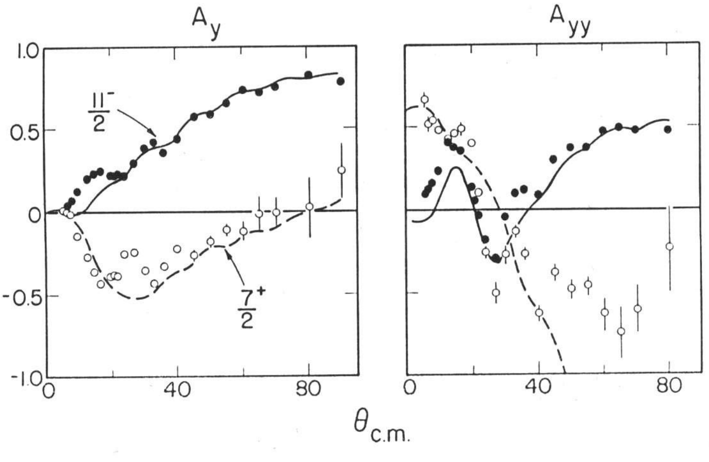

Fig. 1. Measurements of A_y and A_{yy} for the $^{116}Sn(d,p)^{117}Sn$ reaction to the $7/2^+$ (0.71 MeV) and $11/2^-$ (0.32 MeV) states initiated with 79-MeV deuterons. The calculations are described in the text.

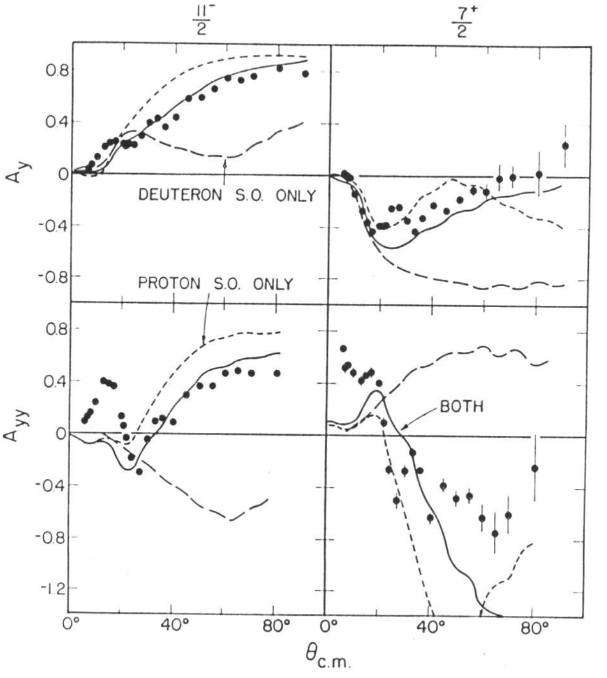

Fig. 2. The measurements of Fig. 1, along with S-state only calculations including spin-orbit distortions for the proton only (short dash), deuteron only (long dash), or both (solid) channels.

The departures of the analyzing power trends from these simple expectations, including the A_{yy} j-dependence, arise from spin-orbit forces, whose effects increase with bombarding energy. Figure 2 illustrates the same measurements, this time with test calculations (deuteron S-state only) in which either the proton or deuteron spin-orbit potential has been removed. The effects follow the rank of the observable, being j-independent for A_y and j-dependent for A_{yy}. The combined calculation appears to be the result of a cancellation between the effects of proton and deuteron spin-orbit potentials in which the proton is clearly more influential.

The sign of the spin-orbit effect in each case depends on whether the spin-orbit potential helps or hinders momentum matching on the far side of the nucleus. The mass difference between the deuteron and proton makes the entrance and exit momenta mismatched at these energies even for large ℓ-transfer. The match can be improved if the transfer takes place when the proton is in its optical potential well (increasing the momentum) and the deuteron is not. In a reaction calculation with consistent optical potential geometry, this condition can only be brought about with spin-dependent distortions. For the deuteron on the nuclear far side, the potential depth is reduced when the deuteron spin is down. Likewise, the outgoing proton potential depth is increased for spin up. When more than one spin state combination can couple to a given transition, this rule will dictate which has the larger amplitude.

The spin-orbit effects of Fig. 2 follow this rule. Since the proton distortions favor spin up, the effects on A_y will be positive in all cases. With the $j=\ell+1/2$ transition, the proton spin orbit favors deuteron spin up over m=0, thus making A_{yy} positive. Likewise, for $j=\ell-1/2$, m=0 will be favored over deuteron spin down, and A_{yy} will be negative. In a similar argument, a coupling which favors deuteron spin down will shift A_y negatively. The A_{yy} trends will again be j-dependent, with A_{yy} being positive for $j=\ell-1/2$ and negative for $j=\ell+1/2$. The proton spin orbit is more influential because it is instrumental in refracting the proton distorted waves about the nuclear far side, and enhancing the momentum match by making the deuteron and proton momenta locally colinear.

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