

TRANSFER REACTIONS

REACTION MECHANISM STUDY OF THE $\ell=0$ GROUND-STATE TRANSITION IN $^{116}\text{Sn}(d,p)^{117}\text{Sn}$

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Because the Distorted Wave Born Approximation (DWBA) often fails at intermediate energies to give a reliable description of transfer reactions,¹ we made extensive polarized-beam measurements of one transition in the hope that it would yield clues to the cause of the difficulties. We chose the $^{116}\text{Sn}(d,p)^{117}\text{Sn}$ transition to the ground state of ^{117}Sn for the following four reasons:

1. The stability and abundance of the final nucleus, ^{117}Sn , permitted us to study the time-reversed reaction as well with a polarized beam. Similarly, we measured the elastic cross section and vector analyzing power for both the entrance and exit channels. This provided us with seven angular distributions which will be used to constrain the optical potentials and to test the transfer reaction calculations.
2. Because this transition has $\ell=0$, the vector analyzing power for the transfer reaction can arise in standard DWBA only from the spin-dependent potentials in the entrance and exit channels. Johnson² has pointed out that, to the extent that the spin-dependence can be treated as a perturbation on the central potentials, the deuteron vector analyzing power (A_y) and proton polarization (p) are linear combinations of two quantities (s_p and s_d) that depend only on the spin-dependence in the proton or deuteron channels, respectively, as

$$A_y = s_p + s_d$$

$$p = 3s_p/2 + s_d$$

- Sample calculations from this reaction show that the approximation is good where the magnitudes of s_p and s_d are not close to 1. A measurement of both the (d,p) and (p,d) analyzing powers permits us to extract s_p and s_d , and from the quality of their theoretical reproduction to infer the quality of the spin-dependent potentials in each channel.
3. Generally, the DWBA encounters its greatest difficulty reproducing transfer reaction data for transitions that are momentum mismatched. At 80 MeV, the mismatch is large when $\ell=0$. Unlike the $\ell=0$ transition in $^{24}\text{Mg}(p,d)^{23}\text{Mg}$ (studied in Ref. 1), this transition does not have a Q -value that leads to an anomalously deep well for the bound particle wavefunction.
 4. Similarly extensive measurements of this reaction are available at other energies (Cadmus at 8.22 MeV,³ Lapointe at 12 and 15 MeV,⁴ and Ohnuma at 22 MeV⁵ and 55 MeV⁶). These data will permit us to investigate the quality of the calculations with changing bombarding energy.

The data were taken with the QDDM magnetic spectrometer. Deuteron elastic scattering and the (d,p) reaction were measured at 79.0 MeV bombarding energy with a 4.8 mg/cm² ^{116}Sn target. The target was kept thin to improve the (d,p) reaction resolution, which was about 50 keV after dispersion matching. A (d,p) spectrum taken at 15° is shown in Fig. 1. The cross section for the ground state transition is

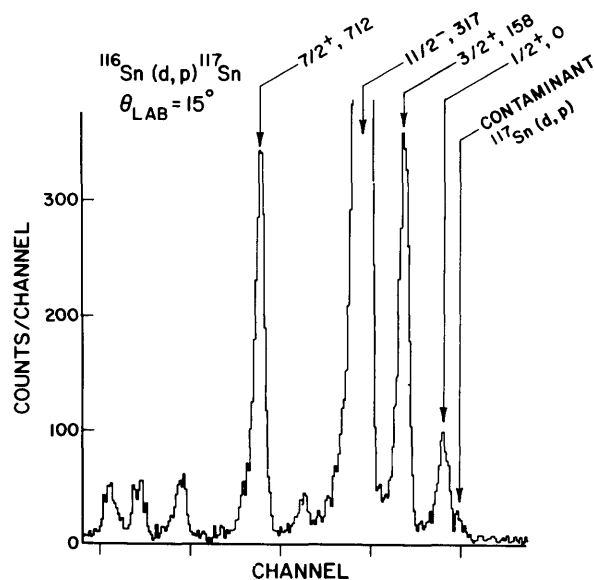


Figure 1. Focal plane position spectrum for $^{116}\text{Sn}(d,p)^{117}\text{Sn}$ at 15° . The major excited states are noted by their spin, parity, and excitation energy in keV.

suppressed by momentum mismatching relative to the excited states of higher spin. There are also contaminants from isotopic impurities in the target. One contaminant peak is clearly visible next to the ground state peak. The inverse (p,d) reaction and proton elastic scattering were measured with a polarized proton beam energy of 83.2 MeV. The target thickness, 14.5 mg/cm^2 , was increased to improve the counting rate. The measured (d,p) and (p,d) cross sections obey detailed balance.

A preliminary analysis of the deuteron and proton elastic scattering cross section and vector analyzing powers is shown in Figs. 2 and 3. The curves are guides to the eye. These data will be used in an optical model analysis to obtain wavefunctions for use in subsequent DWBA calculations.

Prior to the experiment, preliminary zero-range DWBA calculations were made with global potentials from Daehnick⁷ for deuterons and from Schwandt⁸ for protons.

This calculation, normalized by a spectroscopic factor of $S=0.54$, is shown by the solid line in Fig. 4 along with the (d,p) and (p,d) data. The disagreements are severe, especially for the cross section.

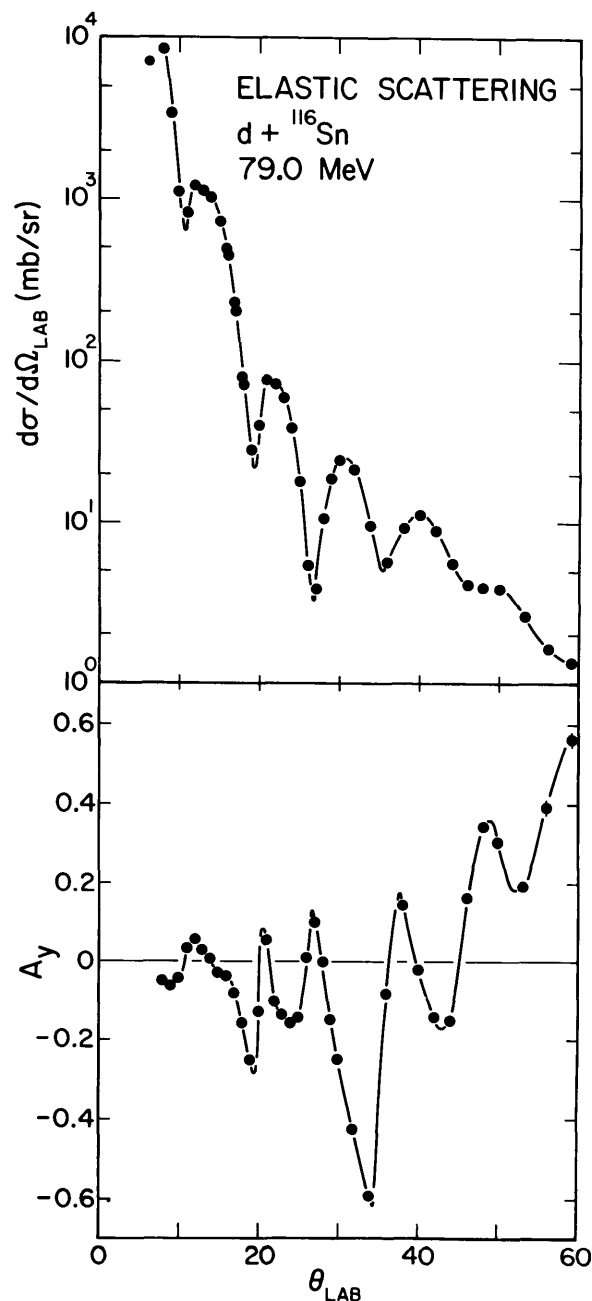


Figure 2. Preliminary measurements of the cross section and vector analyzing power (A_y) for deuteron scattering from ^{116}Sn at 79.0 MeV. The curves are a guide to the eye.

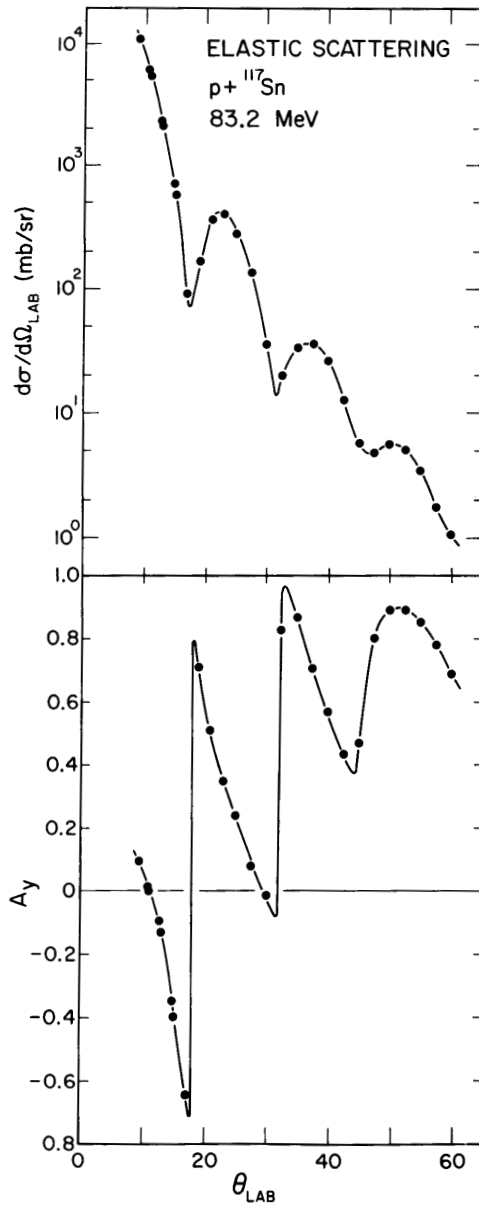


Figure 3. Preliminary measurements of the cross section and vector analyzing power for proton scattering from ^{117}Sn at 83.2 MeV. The curves are a guide to the eye.

It has been recently pointed out that Dirac distorting potentials would lead to substantial attenuation of the contribution from the nuclear interior in the DWBA integrals.⁹ The DWBA calculation was repeated with a Woods-Saxon radial cutoff ($r=1.35$

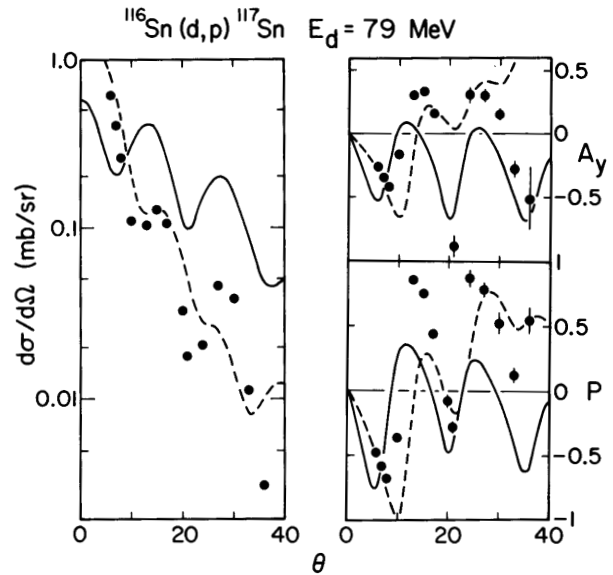


Figure 4. Preliminary measurements of the $^{116}\text{Sn}(d,p)^{117}\text{Sn}$ cross section, vector analyzing power (A_y), and outgoing polarization (p). The curves are zero-range DWBA calculations with (dashed) and without (solid) a radial cutoff.

and $a=0.7$) to simulate such attenuation, and the result is given by the dashed line in Fig. 4. This calculation is substantially different, indicating that a large contribution to the DWBA integral comes from the nuclear interior. While the cross section at forward angles seems better reproduced by a radial cutoff, there is little consistent improvement for the analyzing powers.

Analysis of the experiments at lower energy^{5,6} indicates that reasonable agreement can be obtained with full finite range DWBA calculations that use an adiabatic potential¹⁰ to take into account the effects of deuteron breakup. It was also learned that the channel spin quantities, s_p and s_d , are sensitive to the D-state of the deuteron, although the D-state contributions nearly cancel in A_y and p . The experiments at lower energy^{5,6} indicate that D-state effects increase in importance as the bombarding energy

increases. At 80 MeV, both s_p and s_d have excursions in magnitude to values greater than 1. Comparisons to lower energy measurements suggest that the D-state may account for as much as half of their magnitude. It is thus possible that deuteron D-state effects cannot be neglected in our analysis of the analyzing powers.

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$(f7/2)^{-2}_{7,0}$ CONFIGURATION HIGH-SPIN STATES IN ^{60}Co STRONGLY EXCITED IN THE $^{62}\text{Ni}(d,\alpha)$ REACTION

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As part of our study of high-spin states in the nickel region, preferentially excited in the (d,α) reaction at 80 MeV bombarding energy, we analyzed the $^{62}\text{Ni}(d,\alpha)^{60}\text{Co}$ reaction. From the characteristic shapes of the differential cross sections and vector analyzing power angular distributions^{1,2}, the transferred orbital and total angular momenta L and J were determined for the strongly populated states in ^{60}Co up to an excitation energy of 5 MeV.

From our analysis, eleven $L=6$ transitions were observed, two leading to $J^\pi=6^+$ states at 1.23 and 1.38 MeV and nine leading to $J^\pi=7^+$ states at 1.51, 3.09, 3.46, 3.67, 3.78, 4.04, 4.55, 4.70 and 4.89 MeV. The 6^+ states can be reached in the (d,α) reaction by picking up a proton-neutron pair in the stretched $(1f7/2, 1f5/2)_{6,0}$ configuration. Other stretched pickup configurations, such as the $(1g9/2, 1d3/2)_{6,0}$ configuration, are highly improbable, since the occupation number of the $1g9/2$ orbital in the ground state wave function of ^{62}Ni is very small. This

suggests that the wave function of the 6^+ states at 1.23 and 1.38 MeV have considerable components of the character $[(^{62}\text{Ni}_{g.s.})_{0^+} \otimes (1f^{-1}_{7/2}, 1f^{-1}_{5/2})_{6,0}]$. For the transitions to the 7^+ states, the proton-neutron pair is picked up in the stretched $(1f7/2)^2_{7,0}$ configuration. Transfers in the stretched $(1g9/2, 1d5/2)_{7,0}$ configurations are very unlikely for the same reason as above. From this we conclude that the wave functions of the observed 7^+ states have significant components of the character $[(^{62}\text{Ni}_{g.s.})_{0^+} \otimes (1f7/2)^{-2}_{7,0}]$. Under the assumption that no other transfer configuration is interfering with the $(1f7/2)^2_{7,0}$ configuration, the magnitude of the differential cross section is proportional to the square of the matrix element $\langle \Psi(^{60}\text{Co}^*) | (1f7/2)^{-2}_{7,0} | \Psi(^{62}\text{Ni}_{g.s.}) \rangle$ which can be obtained from a description of the initial and final states in a nuclear model. The distribution of the relative 7^+ transition strength among the various levels, corrected for the Q -value dependence, is displayed in Fig. 1. The strength is spread over nine