

POLARIZATION TRANSFER IN INELASTIC PROTON SCATTERING FROM ^{12}C AND ^{16}O

A.D. Bacher, J.D. Brown[†], M.S. Cantrell^{††}, V.R. Cupps, J.A. Gering, W.P. Jones, D.A. Low, C. Olmer, A.K. Opper, P. Schwandt, A. Sinha, E.J. Stephenson, and S.W. Wissink
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

The in-plane polarization transfer coefficients D_{LL}' , D_{LS}' , D_{SL}' and D_{SS}' have been measured for the 200 MeV proton inelastic excitation of the 1^+ , $T=0$ state in ^{12}C (12.71 MeV), and the 4^- , $T=0$ (17.79 and 19.80 MeV) and 4^- , $T=1$ (18.98 MeV) states in ^{16}O . These measurements use the IUCF spin precession system, high-energy beam-line polarimeters and QDDM focal-plane polarimeter. In addition, cross-section and analyzing-power angular distributions have been measured for these transitions in ^{16}O ; the σ and A data for the transition in ^{12}C were measured previously.¹ (The polarization transfer data presented in this manuscript are preliminary; final analysis of the focal-plane polarimeter analyzing power is in progress and the present results are expected to be accurate to ~10%.)

The main goal of this study is to exploit the enhanced sensitivity of the polarization transfer coefficients to spin-dependent terms of the effective nucleon-nucleon interaction in order to investigate the spin-dependent isoscalar components of the interaction. For this purpose, we have chosen to study spin-flip transitions for which the nuclear structure is relatively well known: the 1^+ , $T=0$ transition in ^{12}C has been extensively studied and the 4^- transitions in ^{16}O are representative of stretched states whose one-particle, one-hole component can arise from only a single particle-hole configuration. For these cases, the contribution of the spin-independent parts of the interaction is small. All of these transitions have been studied using other probes, such as electron and pion inelastic scattering. The present polarization transfer measurements for ^{12}C span the range from 80 to

250 MeV/c (7° to 22.5° laboratory angle), while the ^{16}O data span the range from 230 to 400 MeV/c (20.5° to 37° laboratory angle). Together, these data should provide a significant test of the momentum-transfer dependence of the spin-dependent terms in the interaction.

Inelastic proton scattering spectra for the $^{16}\text{O}(p,p')^{16}\text{O}^*$ and the $^{12}\text{C}(p,p')^{12}\text{C}^*$ reactions are displayed in Figs. 1 and 2. The ^{16}O spectrum at 28° and the ^{12}C spectrum at 11° were measured at scattering angles near the peak of the 4^- and 1^+ angular distributions, respectively. The transitions of interest are clearly observed superimposed on the nuclear continuum at high excitation energy. Accurate yields for these inelastic transitions can be extracted, and precise values of the polarization transfer coefficients have been deduced. At other scattering angles, the inelastic scattering cross

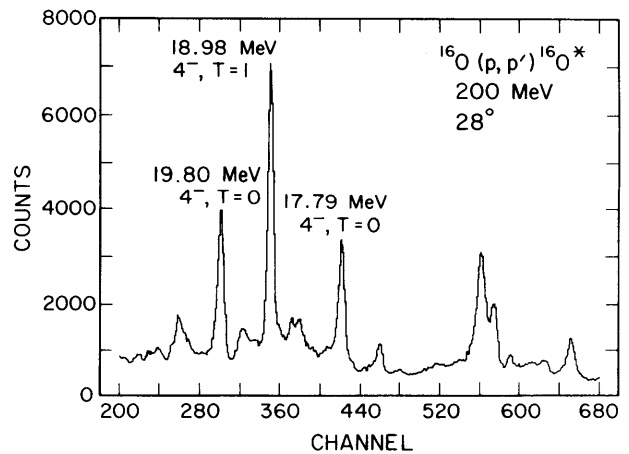


Figure 1. Inelastic proton spectrum for the scattering of 200 MeV protons from ^{16}O . The target employed in the polarization transfer measurements reported here consisted of ^{10}B -enriched boric acid (H_3BO_3); in the high excitation-energy region of interest in ^{16}O , only a flat continuum background was observed for scattering from ^{10}B .

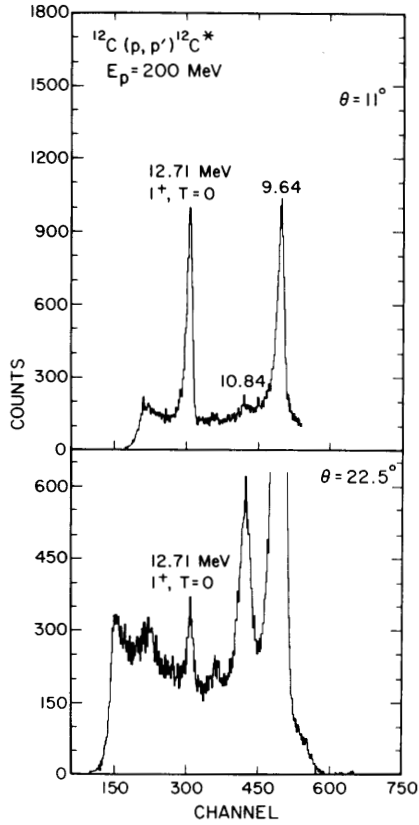


Figure 2. Inelastic proton spectra at laboratory angles of 11° and 22.5° for the scattering of 200 MeV protons from carbon.

sections decrease, but precise measurements of the coefficients remain possible in a reasonable running time as a result of the good position resolution of the focal plane detector, the high efficiency of the focal plane polarimeter and the large intensity of polarized beam available at IUCF. These data for ^{12}C and ^{16}O are currently the most precise polarization transfer measurements for spin-flip inelastic scattering available at intermediate energies.

The resulting polarization transfer data for the 1^+ , $T=0$ transition in ^{12}C are displayed in Fig. 3. The earlier data of McClelland et al.² at 500 MeV are also displayed. The similarity of certain coefficients at

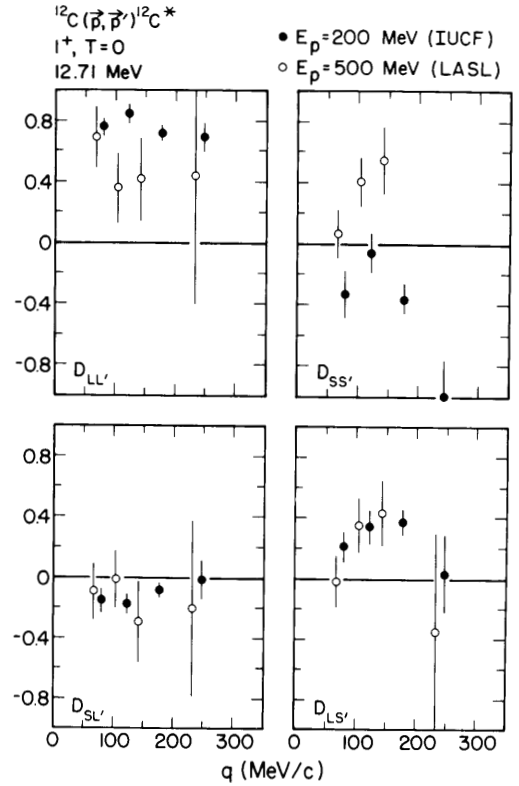


Figure 3. Momentum-transfer dependence of the in-plane polarization transfer data for 200-MeV (solid circles) and 500-MeV (open circles) inelastic proton excitation of the 1^+ , $T=0$ state (12.71 MeV) in ^{12}C . The 500-MeV data are from ref. 2.

the two incident energies is striking (e.g., D_{LS}'), whereas significant differences are observed for other coefficients (e.g., D_{SS}'). These differences reflect changes in the relative importance of the spin-dependent contributions to the reaction. For example, differences resembling those in Fig. 3 result when the tensor interaction is reduced in the presence of a large spin-orbit contribution. Thus, much useful information can also be obtained from a detailed comparison of the polarization transfer data over a large range of bombarding energy.

Distorted-wave impulse approximation (DWIA) calculations^{3,4} have been performed for the ^{12}C and ^{16}O

transitions. The distorted waves were generated from Woods-Saxon optical potentials derived from fits to the proton elastic scattering data. In the ^{12}C calculations, the optical potential⁵ resulted from a simultaneous fit to the elastic-scattering cross-section σ , analyzing-power A and spin-rotation Q data. This potential, which contains an additional squared Woods-Saxon dependence in the real central term, is similar to the published potential⁶ based on an analysis of cross-section and analyzing-power data alone. The ^{16}O calculations employed an optical potential⁷ of similar form based on a fit to the $p+^{16}\text{O}$ elastic σ and A data. The optical-model analyses of Ref. 7 indicated an ambiguity in the extracted potential, such that both a repulsive (DWS+) and an attractive (DWS-) core in the real central potential resulted in an equally good representation of the σ and A data, but gave quite different predictions for Q . The recently measured Q data are not reproduced⁸ by either potential at large scattering angles; at angles forward of 25° , the predictions of the (DWS-) potential are in better agreement with the data. Recent optical-model analyses incorporating the new Q data have, so far, been unable to achieve a detailed reproduction of the new Q results. Since the calculations of the inelastic-scattering polarization transfer coefficients are not especially sensitive to these different optical potentials, we have chosen the optical potential (DWS-) for the ^{16}O inelastic scattering calculations.

The DWIA calculations for the 1^+ , $T=0$ state in ^{12}C employed the Cohen-Kurath wave function⁹, incorporating particle-hole amplitudes for the $p_{3/2}$ and $p_{1/2}$ shells. The three 4^- transitions in ^{16}O are each described by a $(d_{5/2})(p_{3/2})^{-1}$ stretched particle-hole configuration. These transitions have been studied in inelastic

electron and pion scattering experiments.^{10,11} The different strengths observed for the 17.79 and 19.80 MeV transitions in π^+ and π^- scattering have been interpreted¹⁰ in terms of a three-state mixing model. Within this framework, the 18.98 MeV state is shown to be almost pure $T=1$, whereas the 17.79 and 19.80 MeV states are predominantly $T=0$ with $T=1$ mixing such that the lower state is more proton-like and the upper state is more neutron-like. Values for the amplitudes of the mixing are given by ref. 10 as:

$$\begin{aligned} |17.79 \text{ MeV}\rangle &= 0.330 |T=0\rangle - 0.077 |T=1\rangle \\ |19.80 \text{ MeV}\rangle &= 0.348 |T=0\rangle + 0.075 |T=1\rangle \\ |18.98 \text{ MeV}\rangle &= 0.001 |T=0\rangle - 0.620 |T=1\rangle \end{aligned}$$

Calculations^{10,11} using these isospin-mixed wave functions are in agreement with the electron scattering results. These calculations correctly predict the strength of the 17.79 MeV transition and are consistent with the upper limit established for the 19.80 MeV transition observed in the (e,e') studies. Good agreement is also observed in DWIA analyses^{10,11} of the 135 MeV (p,p') cross-section data¹² using these isospin-mixed wave functions. Thus, we can consider that although isospin mixing is present for these transitions in ^{16}O , relatively reliable wave functions which describe the mixing have been independently determined. The sensitivity of these spin observables to the amount of isospin mixing can be evaluated by comparing both pure and isospin-mixed wave functions.

Several different forms of the effective nucleon-nucleon interaction have been examined in this work. These include the Love-Franey¹³ and Paris¹⁴ interactions, both based on the free nucleon-nucleon scattering information, and the density-dependent Paris interaction¹⁴, in which nuclear medium modifications have been included using the local density

approximation. All of these interactions include both direct and knock-on exchange terms exactly; both the direct and exchange contributions are important for these transitions at a bombarding energy of 200 MeV. Although the Love-Franey and Paris interactions are both based on the free nucleon-nucleon scattering information, they involve quite different contributions from central, spin-orbit and tensor components.

The polarization transfer data for the 1^+ , $T=0$ transition in ^{12}C are displayed in Fig. 4. The indicated DWIA calculations employ two recent versions of the Love-Franey interaction (which incorporate the Sp84 and Sm82 phase shifts of Arndt) and the free and density-dependent Paris interactions. The different

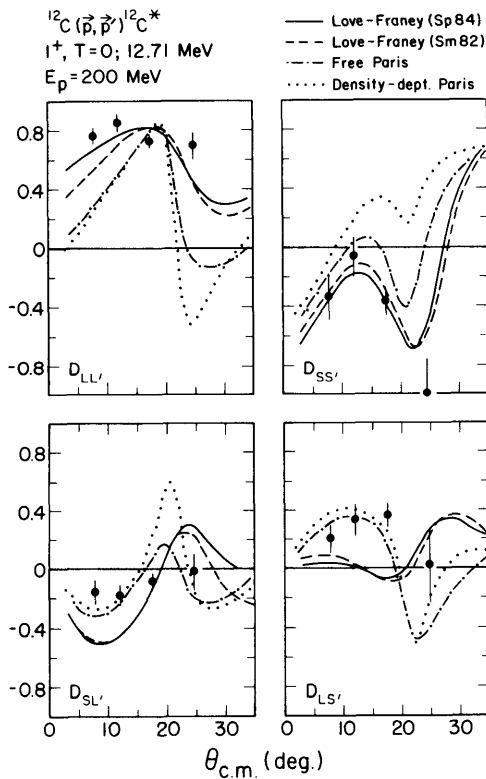


Figure 4. Polarization transfer coefficients for the inelastic proton excitation of the 1^+ , $T=0$ state (12.71 MeV) in ^{12}C . The curves correspond to DWIA calculations using the indicated forms of the effective interaction.

magnitudes and shapes of the polarization transfer coefficients predicted using these different forms of the interaction suggest that measurements of these coefficients can provide a sensitive test of the relative strengths of the spin-orbit and tensor components. However, conflicting conclusions result from these comparisons. The predictions of the Love-Franey interaction are in excellent agreement with the $D_{LL'}$ and $D_{SS'}$ measurements, whereas the Paris-type interactions are in better agreement with the $D_{LS'}$ and $D_{SL'}$ measurements.

The polarization transfer data for the 4^- , $T=1$ transition in ^{16}O are displayed in Fig. 5, together with calculations using the Love-Franey and free Paris

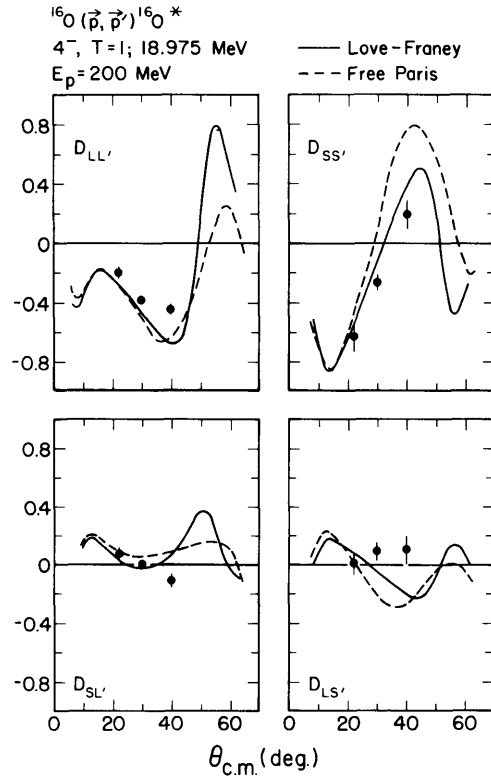


Figure 5. Polarization transfer coefficients for the inelastic proton excitation of the 4^- , $T=1$ state (18.975 MeV) in ^{16}O . The curves correspond to DWIA calculations using the Love-Franey (solid) and free Paris (dashed) interactions.

interactions. (The effects of medium modifications for such high-spin stretched transitions have been shown to be small since the transition densities are localized in the region of the nuclear surface.) An examination of the cross-section predictions indicates that for all the nonrelativistic interactions considered here, the 4^- , $T=1$ transition occurs predominantly by the isovector tensor component. Excellent agreement is observed for the Love-Franey predictions of $D_{LL'}$ and $D_{SS'}$. For either prediction, the agreement for $D_{SL'}$ and $D_{LS'}$ is not as good in the region of large momentum transfer.

The polarization transfer data for the 17.79 MeV and the 19.80 MeV transitions in ^{16}O are shown in Figs. 6 and 7. Significant differences are observed for some of the measured coefficients (e.g., $D_{LL'}$ and $D_{SL'}$) for these two transitions. These differences result from the fact that although the magnitudes of the isospin mixing for these two transitions are similar, the phases are opposite. The similarity of the measured values of $D_{SS'}$ indicates that this observable is probably insensitive to the mixing, a result that is also suggested by the DWIA calculations using the

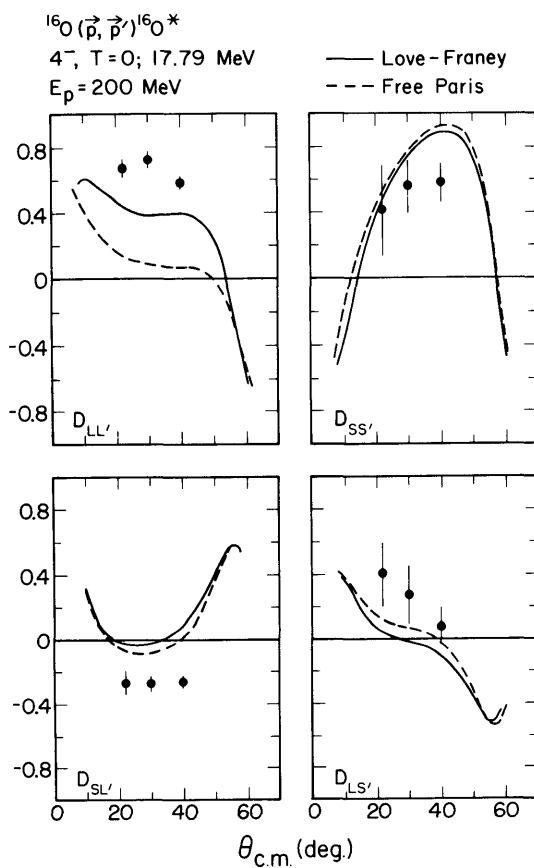


Figure 6. Polarization transfer coefficients for the inelastic proton excitation of the 4^- , $T=0$ state (17.79 MeV) in ^{16}O . The curves correspond to DWIA calculations using the Love-Franey (solid) and free Paris (dashed) interactions.

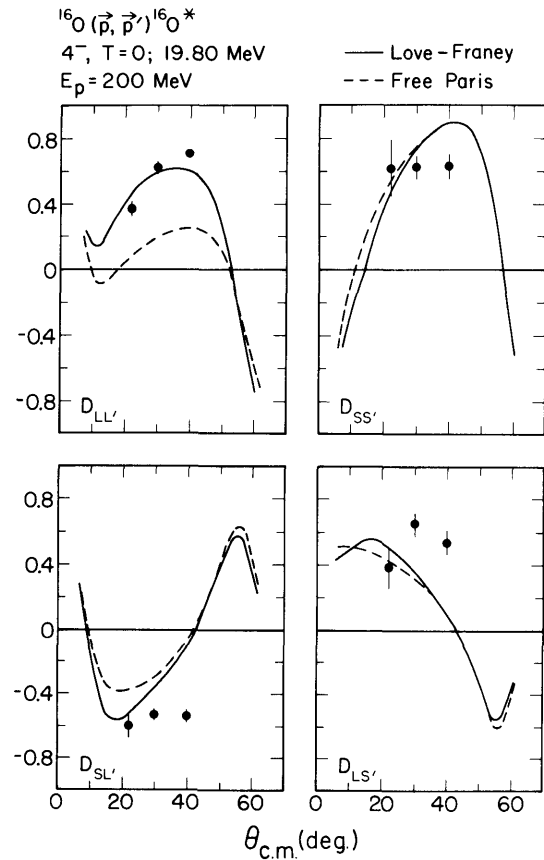


Figure 7. Polarization transfer coefficients for the inelastic proton excitation of the 4^- , $T=0$ state (19.80 MeV) in ^{16}O . The curves correspond to DWIA calculations using the Love-Franey (solid) and free Paris (dashed) interactions.

Love-Franey and free Paris interactions. The main sensitivity of the coefficients to these interactions is exhibited in D_{LL} ; similar predictions are observed for the remaining coefficients. Reasonable agreement of the calculations with the data is seen for some cases.

⁺Present address: Physics Department, Princeton University, Princeton, NJ 08544

⁺⁺Present address: 112 Jamestown Drive, Sunnyvale, CA 94087

- 1) J. Comfort, R. E. Segel, G. L. Moake, D. W. Miller and W. G. Love, Phys. Rev. C 23, 1858 (1981).
- 2) J. B. McClelland, J. M. Moss, B. Aas, A. Azizi, E. Bleszynski, M. Bleszynski, J. Geaga, G. Igo, A. Rahbar, J. B. Wagner, G. S. Weston, C. Whitten, K. Jones, S. Nanda, M. Gazzaly and N. Hintz, Phys. Rev. Lett. 52, 98 (1984).
- 3) R. Schaeffer and J. Raynal, Saclay Report CEA-R4000(1970); modifications by J. Comfort.
- 4) R. Schaeffer and J. Raynal, Saclay Report CEA-R4000(1970); modifications by W. Bauhoff.
- 5) P. Schwandt, private communication.
- 6) H. O. Meyer, P. Schwandt, W. W. Jacobs and J. R. Hall, Phys. Rev. C 27, 459 (1983).
- 7) C. Glover, P. Schwandt, H. O. Meyer, W. W. Jacobs, J. R. Hall, M. D. Kaitchuck and R. P. DeVito, Phys. Rev. C 31, 1 (1985).
- 8) P. Schwandt and E.J. Stephenson, private communication.
- 9) S. Cohen and D. Kurath, Nucl. Phys. A101, 1 (1967)
- 10) D. B. Holtcamp, W. J. Braithwaite, W. Cottingame, S. J. Green, R. J. Joseph, C. Fred Moore, C. L. Morris, J. Piffaretti, E. R. Siciliano, H. A. Thiessen and D. Dehnhard, Phys. Rev. Lett. 45, 420 (1980); J. A. Carr, F. Petrovich, D. Halderson, D. B. Holtcamp and W. B. Cottingame, Phys. Rev. C 27, 1636 (1983); and references therein.
- 11) C. Hyde, Ph.D. thesis, M. I. T. (1984); W. Bertozzi, LAMPF User's Meeting, 1981.
- 12) R. S. Henderson, Ph. D. thesis, University of Melbourne (1979); R. S. Henderson, Aust. J. Phys. 32, 411 (1979).
- 13) W. G. Love and M. A. Franey, Phys. Rev. C 24, 1073 (1981); W. G. Love, private communication.
- 14) H. V. von Geramb and K. Nakano, in The Interaction Between Medium Energy Nucleons in Nuclei - 1982, ed. H. O. Meyer (AIP Conf. Proc. 97, New York, 1983), p. 44.

[→](p,p') REACTIONS ON HEAVY TRANSITIONAL NUCLEI

F. Todd Baker and Anil Sethi
University of Georgia, Athens, Georgia 30602

G.T. Emery and W.P. Jones
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

Previously acquired data for the $^{192}\text{Os}(p,p')$ reaction at 135 MeV have now been expanded to include data for the $^{194,198}\text{Pt}(p,p')$ reactions at the same energy. These new data have been fully reduced but coupled-channels and interacting-boson model (IBM) analyses have not yet been completed. The platinum data are superior in quality to the osmium data (because of more uniform targets nearly free of contaminants); three strongly excited 4^+ states, the

principal focus of these experiments, are clearly seen in each platinum isotope.

IBM analyses of the ^{192}Os data are continuing. The E2 properties of ^{192}Os are well-described by the usual (i.e. with only s- and d-bosons) IBM,¹ but E4 properties, determined using our $^{192}\text{Os}(p,p')$ results, are poorly described. The general thrust of our IBM analyses is to ascertain whether this failure of the IBM is due to neglecting the g-boson degree of freedom.