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Polarization Transfer in 200-MeV Proton Elastic and Inelastic Scattering

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During the past year and a half, IUCF has been making measurements of the in-plane polarization transfer coefficients in 200-MeV proton elastic and inelastic scattering. Data are now available for the spin rotation Q function in elastic scattering from ^{12}C, ^{16}O, ^{40}Ca, and ^{48}Ca. In addition, measurements of the four in-plane transfer coefficients, $D_{LL'}$, $D_{SL'}$, $D_{LS'}$, and $D_{SS'}$, for the 1^+, T=0 and T=1 inelastic transitions in ^{12}C (12.71 and 15.11 MeV) and the 4^-, T=0 and T=1 transitions in ^{16}O (17.79, 18.98, and 19.80 MeV) have been completed. Final analysis of the measurements is still in progress. A discussion of the experiment is contained in a contribution to this conference.[1]

The measurements of the spin rotation function in proton elastic scattering complement previously existing measurements of the cross section and analyzing power.[2-4] These measurements are most often described by an optical potential, based either on the non-relativistic Schroedinger equation (with relativistic kinematics) or the Dirac equation with large cancelling scalar and time-like vector potentials. While phenomenological analyses of both types exist, most recent theoretical efforts have been directed towards obtaining the optical potential through an impulse approximation from nucleon-nucleon potentials. The status of this work has been reviewed by Ray and Hoffmann.[5] They pointed out that the Schroedinger equation approach has difficulty at most bombarding energies between 300 and 800 MeV, and the Dirac approach does well only at the higher energies.

Since that review was published, much of the difficulty at lower energies with the Dirac approach has recently been traced to the use of a pseudo-scalar πNN vertex function, which diverges with decreasing bombarding energies. This difficulty is removed if a pseudo-vector vertex (which gives the same on-shell amplitudes) is substituted. Two groups[6,7] have recently generated optical potentials of this form; their calculations for the ^{40}Ca analyzing power and spin rotation function Q are shown in Fig. 1. Tjon and Wallace[6] have included a large number of amplitudes and invariants, while Horowitz and Murdock[7] have simpler amplitudes and also consider the effects of Pauli blocking. The ground state densities for ^{40}Ca are taken in both cases from Ref. 8. Both calculations successfully describe Q and A. These two approaches diverge with increasing mass,[9] and measurements on a much heavier nucleus are needed to differentiate between the two methods. Additional calculations for ^{12}C and ^{16}O are shown in a contribution to this conference.[10]

Relativistic optical-model calculations usually employ only a vector and scalar potential, even though a tensor potential is allowed. Since the amplitudes can be generated from a meson-exchange model, we can estimate the tensor-potential effects, which are a measure of the interference between the positive and negative energy components in the nuclear ground state wavefunction. A calculation[7] with and without tensor components for ^{48}Ca is shown in Fig. 2. Here the effects should be large because of the tensor density generated by the filled $f_{7/2}$ neutron shell. While the effects are largest for Q, they are still too small to matter at the present level of agreement between theory and experiment.

Agreement within a non-relativistic impulse approximation framework can also be improved through the use of density-dependent corrections based on Pauli exclusion effects and the Fermi motion of the target nucleons. A calculation by Bauhoff[11] for ^{12}C is shown in Fig. 3, where the corrections are essential in reproducing the analyzing power and Q at angles larger than 20°. The quality of these results is comparable to those obtained with the relativistic approach.

While much has been made of the agreement between the 500-MeV elastic scattering data on ^{40}Ca and the relativistic impulse approximation,[5] a preferred approach must be generally successful with a broad range of measurements. In this context, neither method yet stands out. It is clear that a successful treatment must be more sophisticated than those reviewed by Ray and Hoffman, including at least the best

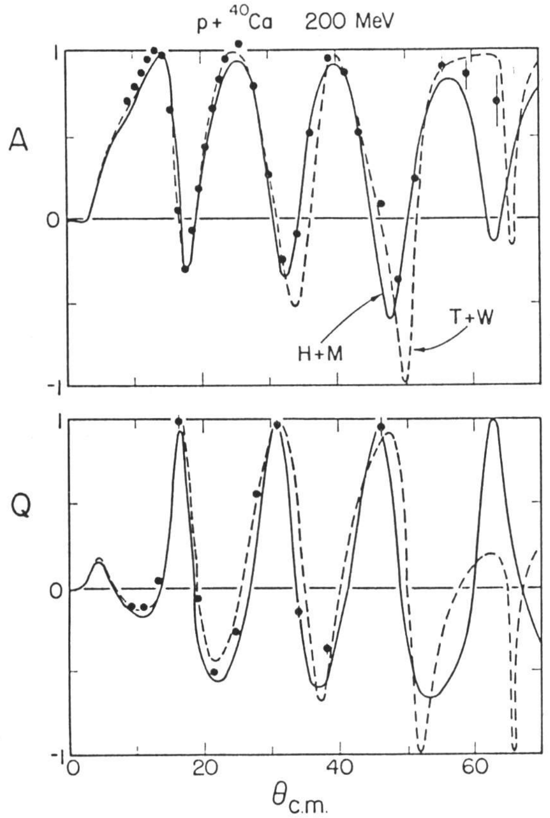

Fig. 1. Measurements of A and Q for ^{40}Ca. The RIA calculations are from Tjon and Wallace[6] (T+W) and Horowitz and Murdock[7] (H+M).

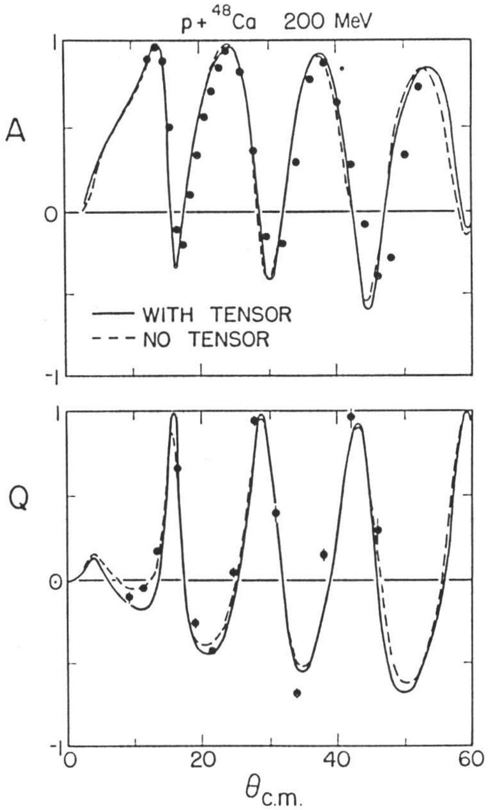

Fig. 2. Measurements of A and Q for ^{48}Ca. The calculations from Ref. 7 were made with (solid) and without (dashed) a tensor potential.

nucleon-nucleon information and a consideration of the effects of the nuclear medium (e.g.: Pauli blocking). Measurements at a broad range of energies will be needed for comparison, with medium effects easily visible at IUCF energies. These measurements are now being made with sufficient precision that they may also be used to extract optical potentials of arbitrary radial shape that may be compared more directly with

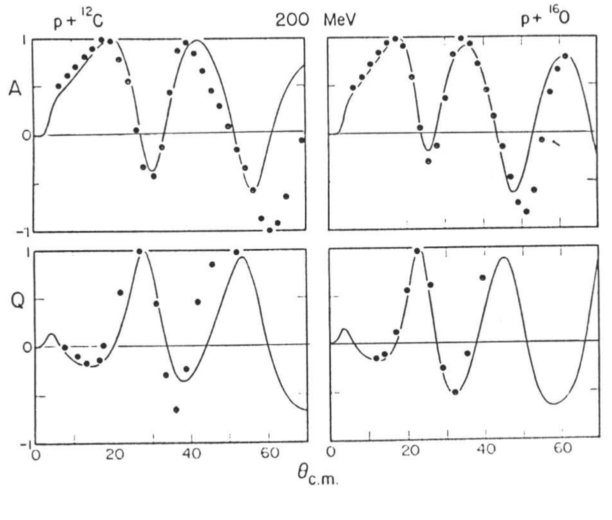

Fig. 3. Measurements of A and Q for ^{12}C. The calculations from Bauhoff[11] were made with (solid) and without (dashed) density dependent corrections.

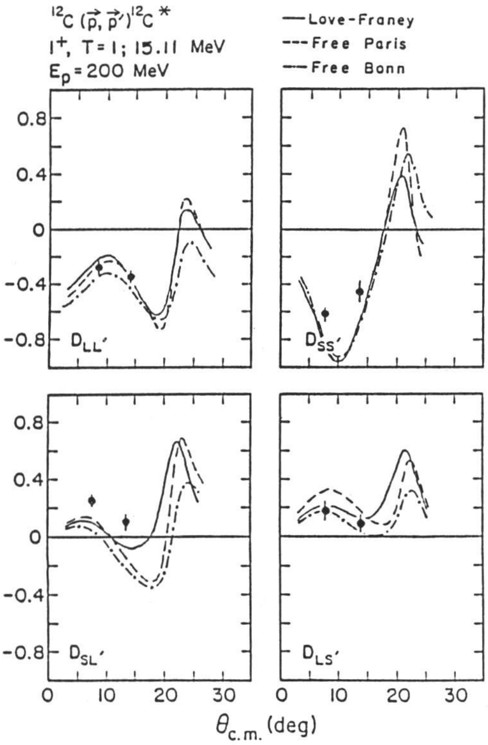

Fig. 4. Polarization transfer coefficients for the 1^+, T=1 state at 15.11 MeV in ^{12}C. The three curves represent the interactions of Love and Franey[14] (solid), Paris[15] (dashed), and Bonn[16] (dash-dot).

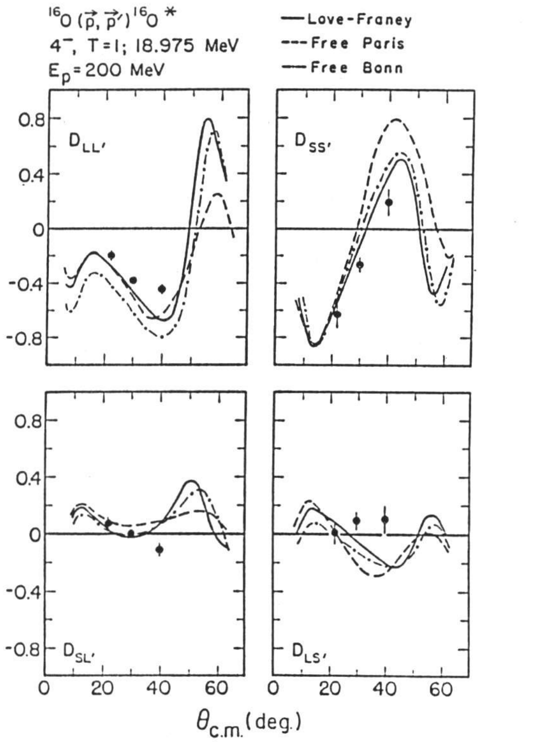

Fig. 5. Polarization transfer coefficients for the 4^-, T=1 state at 18.98 MeV in ^{16}O. The curves are defined in the caption to Fig. 4.

the potentials generated in an impulse approximation approach.

An investigation of inelastic scattering can provide further information on the nucleon-nucleon interaction in the nuclear medium by using the structure of the transition as a filter. We have examined unnatural parity transitions (1^+ in ^{12}C and 4^-in ^{16}O) as a way to increase our sensitivity to the spin-dependent parts (spin-spin, spin-orbit and tensor) of the interaction. The ^{12}C and ^{16}O nuclei were chosen since considerable information is already available on the structure of the excited states, and they have been studied with a variety of probes. The most sophisticated calculations are now made in a non-relativistic impulse approximation (DWIA) approach using the program[12] DWBA81. More information on the input to the calculation is contained in a contribution to this conference.[13]

The interaction for transitions to T=1 final states depends predominantly on the data for the p+p system, and is well determined. This is reflected by the four in-plane polarization transfer coefficients measured for the 15.11 MeV state in ^{12}C (Fig. 4) and the 18.98 MeV state in ^{16}O (Fig. 5). In each case, three interactions are compared (without density-dependent corrections which are small), Love-Franey,[14] Paris,[15] and Bonn.[16] There is little difference among these T=1 predictions and all of them capture the trends of the data.

At the same time there are greater ambiguities for the T=0 interaction, originating in part in the nucleon-nucleon input. One difference among the three interactions examined here appears at large momentum transfer and predominantly in $D_{LL'}$, as shown in Fig. 6. A larger tensor strength present in the Paris interaction pushes $D_{LL'}$ to more negative values, away from the measurements. The Love-Franey and Bonn interactions give comparable agreement. The calculations for the three remaining polarization transfer coefficients do not differ significantly when different interactions are used. The differences between the 17.79 and 19.80 MeV calculations

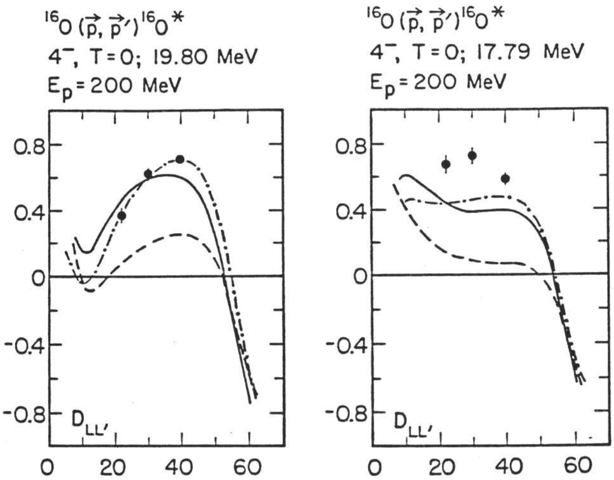

Fig. 6. The polarization transfer coefficient $D_{LL'}$ for the two 4^-, T=0 states at 17.79 and 19.80 MeV in ^{16}O. The curves are defined in Fig. 4.

for $D_{LL'}$ reflect the different isospin mixing assumed for the ^{16}O wavefunctions. There is a greater difference in the calculations than is present in the measurements.

Medium modifications based on Pauli exclusion and Fermi motion effects are available for the Paris and Bonn interactions. Their effects are generally small, but

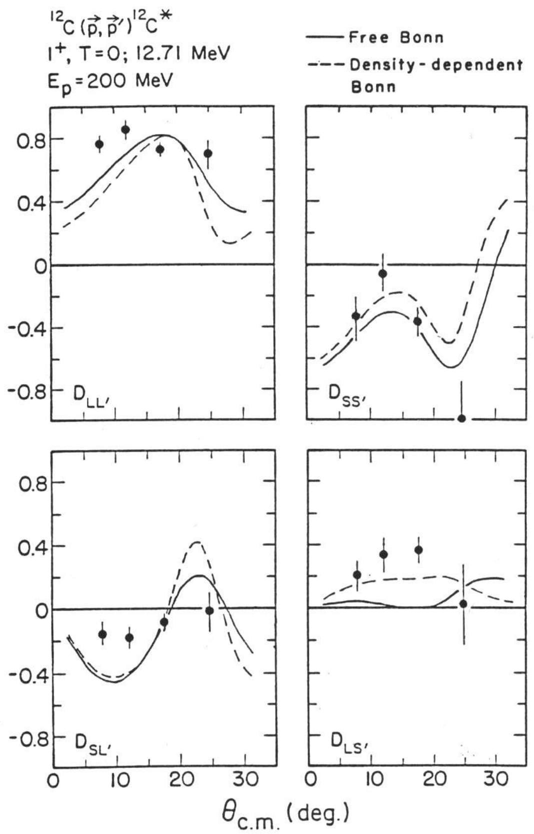

Fig. 7. Polarization transfer coefficients for the 1^+, T=0 state at 12.71 MeV in ^{12}C. The calculations use the Bonn interaction with (dashed) and without (solid) density-dependent corrections.

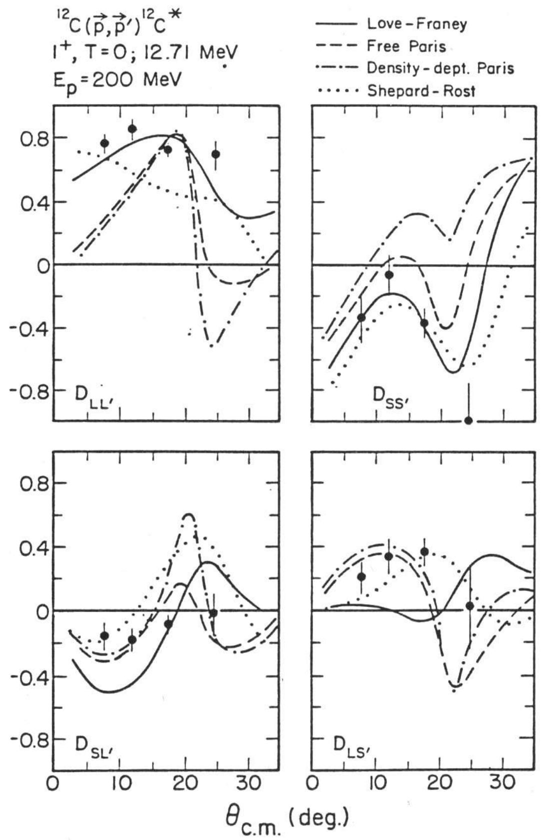

Fig. 8. Polarization transfer coefficients for the 1^+, T=0 state at 12.71 MeV in ^{12}C. The non-relativistic calculations use the interaction of Love and Franey[14] (solid), and Paris[15] with (dash-dot) and without (dash) density-dependent corrections. The dotted curve is the calculation of Shepard.[17]

happen to be more significant for the 12.71 MeV transition in ^{12}C. In Fig. 7 the 12.71 MeV measurements are compared with Bonn interaction calculations made with and without the density-dependent corrections. For D_{LS}, some improvement is noted in the agreement when these corrections are applied. The corrections of the Paris interaction produce similar, although generally larger, changes.

Relativistic (Dirac approach) DWIA calculations are now being developed,[17] but have not yet reached a level of sophistication comparable to the best non-relativistic calculations. At present, explicit exchange contributions to the scattering are omitted, and the transition density amplitudes are taken from a non-relativistic shell model calculation. Nevertheless, an interaction using relativistic invariants is available, and preliminary calculations are shown in Fig. 8. Also included for comparison are the non-relativistic calculations using the interactions of Love and Franey,[14)] and Paris.[15)] Although crude qualitative agreement is obtained in all cases, problems exist and it is premature to judge which calculation will ultimately do the better job. We expect the relativistic DWIA results with exchange to be available shortly.

The high precision of the polarization transfer measurements has provided the first opportunity to examine the spin-dependent features of these interactions in detail. No interaction provides a completely satisfactory representation of all the measurements, including cross section and analyzing power. Some of the difficulty may lie in structure uncertainties, but the generally good qualitative agreement is encouraging.

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DISCUSSION

JOHNSON: How are the distorted waves treated in the inelastic calculations you reported?

STEPHENSON: The distorted waves are generated by an optical model calculation whose parameters were chosen to best reproduce the elastic scattering data. In the case of ^{12}C, this data also included our measurements of Q.

AUSTIN: Do the present calculations well describe the cross sections for the transition to the 12.2 MeV 1^+ state in ^{12}C?

STEPHENSON: No, they don't. I'm sorry I don't have a transparency with me to show you. The use of source of these newer interactions has not resulted in any improvement in the quality of the cross section calculations.