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MODIFICATIONS OF THE EFFECTIVE ISOVECTOR INTERACTION FROM STUDIES OF ($\vec{p},\vec{p}'$) POLARIZATION TRANSFER

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As a result of cyclotron experiments E245 and E306, a complete set of polarization transfer coefficients (D_{ij}), as well as differential cross section, analyzing power (A_y), and induced polarization (P), are now available[1,2] for the 4^- "stretched" $T=0$ and $T=1$ transitions in $^{16}O(\vec{p},\vec{p}')^{16}O$ at $E_p = 200$ MeV. These transitions at 17.79 and 19.80 MeV ($T=0$) and at 18.98 MeV ($T=1$) can be described within the framework of the distorted wave impulse approximation, which models the transition with an effective t-matrix based on NN scattering. The spin transfer ($\Delta S = 1$) required by the dominant $1p_{3/2}^{-1}1d_{5/2}$ character of these transitions emphasizes their sensitivity to the spin-orbit and tensor parts of the t-matrix. Various interactions[3,4] based on free NN scattering (phase shifts or potentials) often agree with each other but not with the measurements, giving several systematic discrepancies[1,2] with the polarization transfer observables. Because the "stretched" transitions occur predominantly in the low density of the nuclear surface, interactions[4] that correct for Pauli blocking in the nuclear medium have little effect on these calculations.[2]

In a recent article, Brown and Rho[5] have suggested additional modifications to the isovector interaction in the nuclear medium. These may be characterized as an increase in the ρ-meson coupling and a decrease in the ρ-meson mass in proportion to the change in the nucleon effective mass (from m to m^*). Here, we will illustrate a change to the effective isovector interaction that removes the discrepancies for the $T = 1$ transition and compare this change quantitatively with the Brown and Rho suggestion.

The calculations we are reporting were made with the impulse approximation program DW86.[6] The distorted waves in the entrance and exit channels were calculated using an Dirac optical potential adjusted to reproduce the cross section, analyzing power, and spin rotation data for the elastic scattering of 200-MeV protons from ^{16}O (ref. 7). The potential parameter optimization was made using the program RUNT,[8] and the Schrödinger equivalent potential[9] was used in DW86. The free interaction taken as the basis for this study was from Franey and Love.[3]

The output from DW86 was arranged to provide observables for separate pieces of the interaction as well as their real and imaginary cross terms. These sets of observables were combined in a second program to yield a final set equivalent to the altered interaction t',

$$t' = a_0 t + a_1 \delta t_1 + a_2 \delta t_2 + \dots \quad , \tag{1}$$

where t was the original interaction, δt_i modifications to it, and a_i adjustable coefficients. This program compared the observables with the data for the 18.98 MeV, $T = 1$ transition, adjusting the coefficients to best reproduce the data. Comparison with the calculation was always made to either the cross section or the product of the cross section and a polarization observable. During the adjustment, a_0 was real while the remaining coefficients were allowed to be complex.

Modifications to ρ-meson exchange should appear in the isovector term of the tensor interaction, t^T_τ, and the vector-isovector term of the central interaction, $t^C_{\sigma\tau}$. Using a model that will be discussed in the next section, forms were chosen for δt_1 and δt_2 that modelled the q-dependence of the ρ-meson contribution in the tensor and central interactions, respectively. Using the effective range expansion and values of R from among those used in ref. 3

$$\delta t_1 = \delta t^T_\tau = 5 \times 10^4 \;\; 32\pi \, \frac{q^2 R^7}{[1 + (qR)^2]^3} \; , \qquad R = 0.15 \text{ fm} \tag{2}$$

$$\delta t_2 = \delta t^C_{\sigma\tau} = 50 \;\; 4\pi \, \frac{R^3}{1 + (qR)^2} \; , \qquad R = 0.25 \text{ fm} \tag{3}$$

where the normalization was chosen to give values of a_i near unit magnitude in the adjustment process.

Final values of the a_i coefficients are shown in Table I. The errors include contributions from both the statistical precision of the measurements as well as the quality of agreement in the final calculation. The value of a_0 was close to one; departures from one may reflect experimental normalization errors as well as true changes in the interaction. The signs of the real parts of a_1 and a_2 are consistent with a stronger ρ-meson contribution in the medium. While imaginary pieces are crucial in the parameter adjustment, there is no guidance from the simple idea of increased ρ coupling for an interpretation of these values.

Table I: Coefficients for the Altered Interaction

	real	imaginary
a_0	1.08 ± 0.05	
a_1 (tensor)	-0.32 ± 0.09	-0.52 ± 0.14
a_2 (central)	0.12 ± 0.05	-0.12 ± 0.09

Figure 1 shows each observable. The dashed curves are the calculations based on the free interaction of Franey and Love. The solid curves show the effect of altering the interaction. The reproduction of each observable is either unchanged or improved, with the best results obtained for the analyzing power (A), the diagonal polarization transfer coefficients ($D_{NN'}$, $D_{LL'}$ and $D_{SS'}$), and $D_{LS'}$.

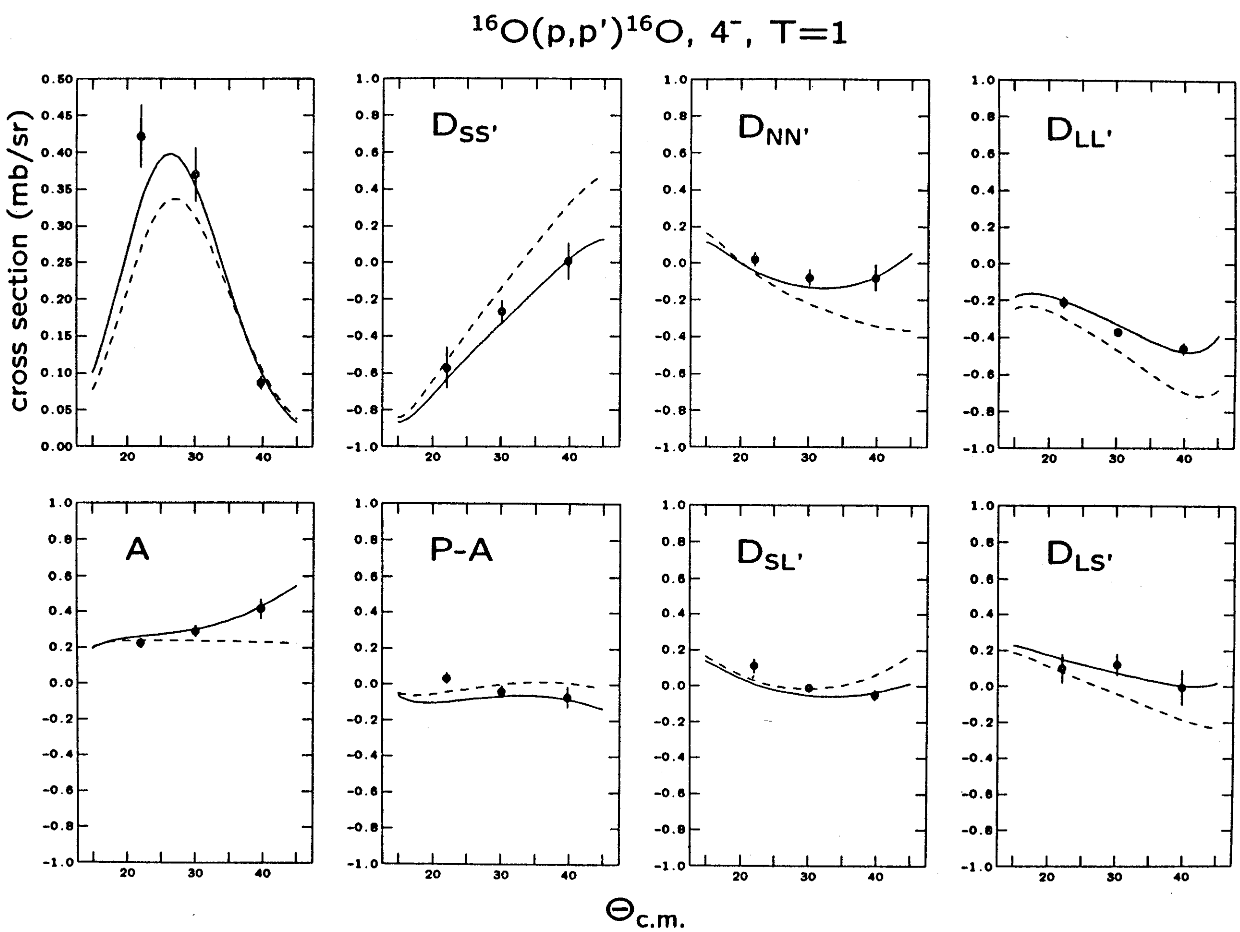

Figure 1. Measurements of the cross section and polarization observables for the $^{16}O(\vec{p},\vec{p}')^{16}O$ reaction to the 4^-, $T = 1$ state at 18.98 MeV. The dashed curve represents calculations made with the free Franey-Love interaction; the solid curve includes modifications to the isovector terms.

Figure 2 shows the changes to $t^C_{\sigma\tau}$ and t^T_τ from equations (2) and (3). The real part moves from the dot-dash (Franey and Love[3]) to the solid line; the imaginary from the short to the long dashed line. The changes are largest for t^T_τ at larger momentum transfer. Noting that the horizontal axis in Fig. 2 represents momentum transfer in the NN center-of-mass, the direct part of the transition matrix is sensitive to momentum transfers near 1 fm^{-1} where the changes are modest, and the exchange part is sensitive to values near 3 fm^{-1}. Calculations confirm that the bulk of the changes in figure 1 arise from the exchange portion of the transition matrix, making formulations[10] based on plane-wave, direct assumptions nearly useless as a guide.

To make the connection with modifications of the ρ-meson, we will write a simple meson-exchange potential[11] for $t^C_{\sigma\tau}$ and t^T_τ and scale it for short-range screening (using coefficients α and β) until it matches the Franey and Love[3] interaction in Fig. 2. The reproduction will not be perfect, since we are assuming in effect that the phenomenological t-matrix contains contributions only from π and ρ exchange. Nevertheless, we will compare

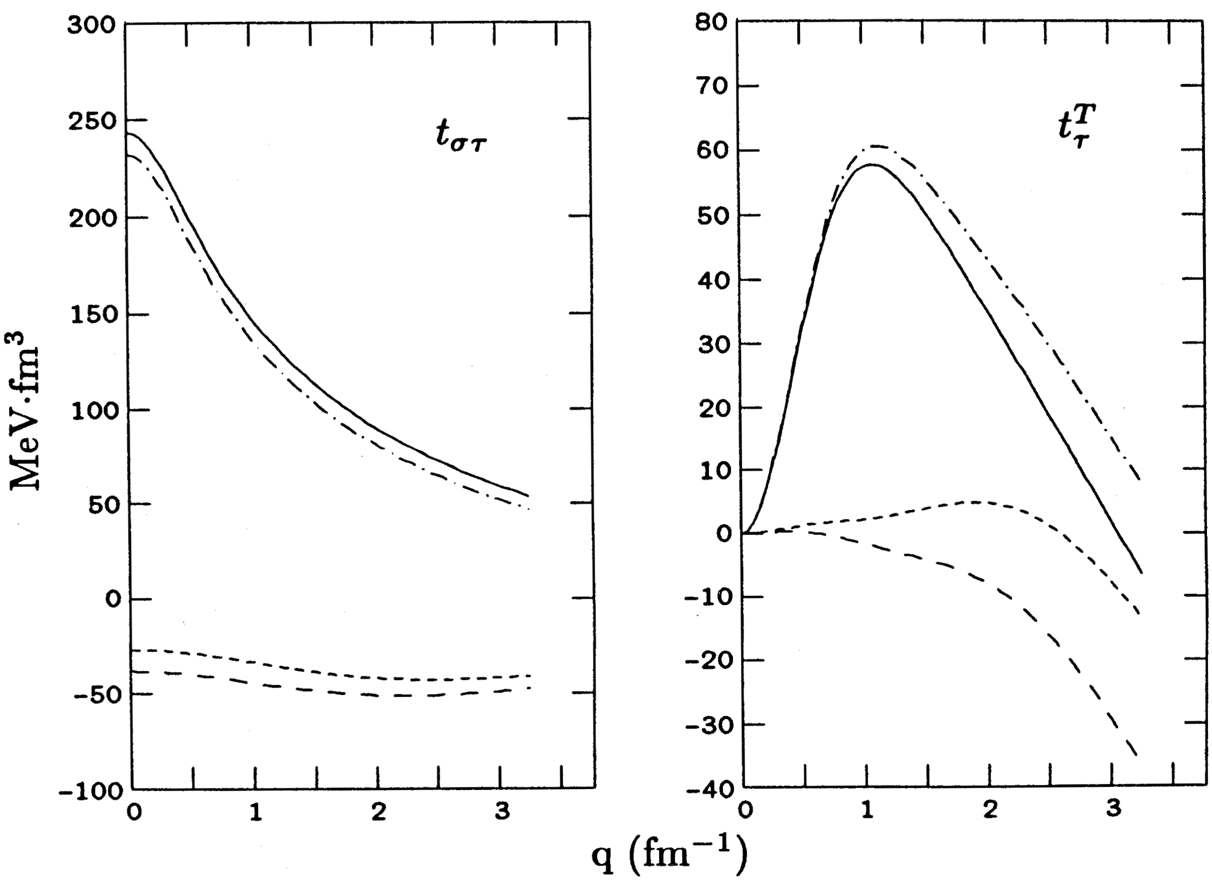

Figure 2. Values of the t-matrix terms $t^C_{\sigma\tau}$ and t^T_τ as a function of the NN momentum transfer. Both the Franey-Love (real=dot-dash, imaginary=short dash) and modified (real=solid, imaginary=long dash) values are shown.

the *changes* in the empirical t-matrix with the *changes* in the potential model as a function of m^*/m. Because of the ranges selected in equations (2) and (3), the reproduction of the q-dependence of these changes is excellent. The size of the screening coefficients α and β sets the scale for interpreting the changes in terms of the model parameter m^*/m.

The tensor potential is

$$V_T = \alpha\,\frac{1}{3}\left(\frac{f_\pi^2}{m_\pi^2}\frac{q^2}{q^2+m_\pi^2} - \frac{f_\rho^2}{m_\rho^2}\frac{q^2}{q^2+m_\rho^2}\right) S_{12}(\hat{q})\ \tau_1{\cdot}\tau_2, \qquad \alpha = 0.7 \tag{4}$$

and the central potential is

$$V_C = \alpha\,\frac{1}{3}\left(\frac{f_\pi^2}{m_\pi^2}\frac{m_\pi^2}{q^2+m_\pi^2} + \beta\ 2\frac{f_\rho^2}{m_\rho^2}\frac{m_\rho^2}{q^2+m_\rho^2}\right) \sigma_1{\cdot}\sigma_2\tau_1{\cdot}\tau_2, \quad \alpha = 0.7, \quad \beta = 0.3\,. \tag{5}$$

The equation for V_C has the contact term removed. A similar value for β may be found in Speth.[12] The coupling constants were chosen following Brown and Rho[5] to be $f_\pi^2/m_\pi^2 = 0.08$ and $f_\rho^2/m_\rho^2 = 2\ f_\pi^2/m_\pi^2$. Since we match to the empirical t-matrix, more recent values of the coupling constants[13] will only change the screening coefficients.

Since the values of a_1 and a_2 were determined independently, each may become the basis for a value of m^*/m, thus giving a check in the internal consistency of the model. For this comparison, we chose to vary only the ρ-meson coupling constant and not the ρ mass, in accord with the calculations discussed in Brown and Rho.[5] The results are:

$$\frac{m^*}{m} = 0.954 \pm 0.021\ (V_C), \quad = 0.915 \pm 0.025\ (V_T), \quad = 0.938 \pm 0.016\ (\text{avg.}). \tag{6}$$

We find that the model parameter m^*/m is determined consistently from the changes to $t_{\sigma\tau}^C$ and t_τ^T. Choosing to vary the ρ-meson mass as well would have resulted in values closer to one. Our values are larger than the Brown and Rho estimate of 0.75 because we are observing a "stretched" surface transition in a light nucleus, and the density is much less than would be expected for nuclear matter.

Through exchange, we expect that these changes will influence calculations for $\Delta T = 0$. An examination of these transitions in ^{16}O(p,p$'$)^{16}O is underway.

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