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ANALYZING POWERS FOR THE PROTON EXCITATION OF HIGH-SPIN STATES IN ^{28}Si:
A NEW LOOK AT THE EFFECTIVE INTERACTION

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One of the outstanding new features of inelastic proton scattering at intermediate energies has been the observation of high-spin states of simple structure, that are excited primarily through the non-central components of the effective nucleon-nucleon inter-action.[1-6] In the present work, analyzing powers $A_y(\theta)$ have been measured for 135 MeV $(\vec{p},p')$ excitation of the 5$^-$, T=0 (9.70 MeV), 6$^-$, T=0 (11.58 MeV), and 6$^-$, T=1 (14.35 MeV) states in ^{28}Si. Differential cross sections for transitions of this nature have provided definitive information on the strength of the high-momentum components of the non-central parts of the effective interaction,[4-6] and generally confirm the validity of the impulse approximation.[7]

For the three states of interest, the differential cross sections, analyzing powers, and their products are shown from top to bottom in Figs. 1 and 2. While the shapes of the cross-section angular distributions are quite similar, the analyzing-power angular distributions are distinctly different and provide a definite signature of the spin and isospin transfer for each transition. The curves in Figs. 1 and 2 are the result of distorted-wave impulse approximation (DWIA) calculations. These calculations used the complex central and real spin-orbit components of the two-nucleon t-matrix interaction[8] supplemented by a real tensor interaction.[9,10] The imaginary parts of t^{LS} and t^T, which have been neglected, are small.[8] Optical-model parameters were taken from Schwandt
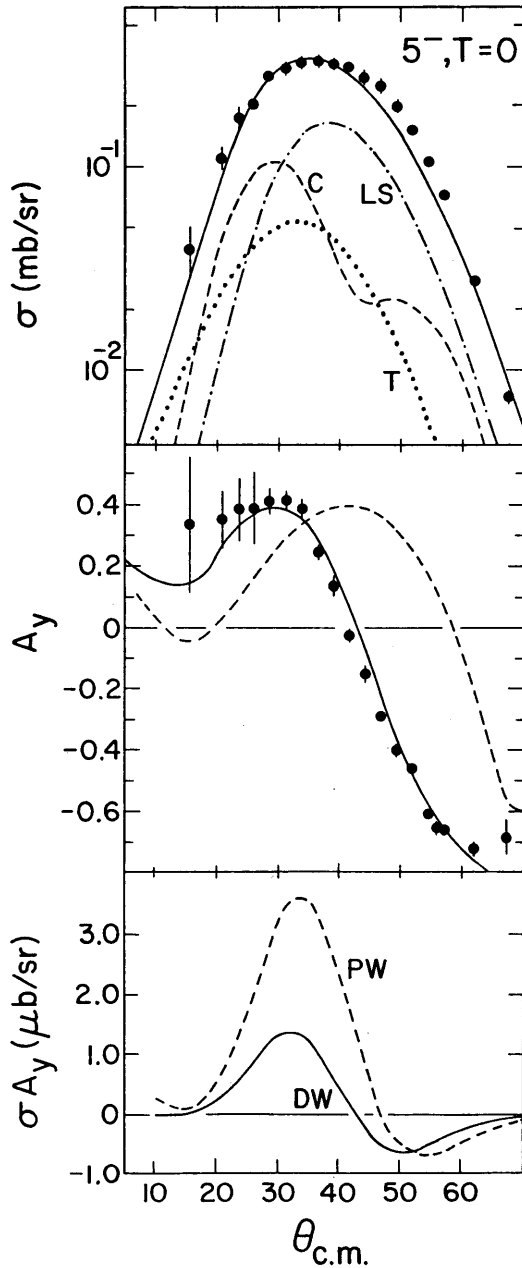
Figure 1. Results of cross section and analyzing power measurements, and calculations, for the 5⁻ T=0 state of ^{28}Si at 9.70 MeV. In each part the full curve shows the result of the full DWIA calculation, using the transition amplitude described in the text, which describes well the experimental (e,e') results of ref. 12; in the differential cross section plot the calculated results have been divided by a factor of 2.0. The dashed line plotted for the analyzing power is the result of a DWIA calculation in which the imaginary part of the central term in the effective interaction has been replaced by one that is of short range in configuration space, and thus constant in momentum transfer. The effect of distortions on the product σA is shown in the lower part of the figure.

et al.[11] The (p,p') calculations[12] for the 5⁻ state shown in Fig. 1 employed the shell-model configuration

$$0.966\ (f_{7/2}d_{3/2}^{-1}) + 0.234\ (f_{7/2}d_{5/2}^{-1}) -$$
$$0.161(f_{5/2}d_{5/2}^{-1})$$

which was deduced in a recent electron-scattering experiment.[13] The DWIA, using this transition amplitude, uniformly overestimates the differential cross section by a factor of 2.0. Similar renormalizations have been observed for other natural-parity transitions,[4,14] and may be symptomatic of the need to include Pauli-blocking corrections in the effective interaction.

For this 5⁻ transition, where the spin-flip and current contributions can be neglected, the analyzing power in the plane-wave impulse approximation (PWIA) is given by[15]

$$A_y\ (\theta) = \frac{2t_R^{LS}t_I^C - 2t_I^{LS}t_R^C}{|t^C|^2 + |t^{LS}|^2}$$

This expression clearly shows that the analyzing power contains information about the interference between the spin-orbit and central terms in the effective interaction which is not contained in the differential cross section. In this case we expect large analyzing powers because both the real part of the spin-orbit and the imaginary part of the central terms are substantial.[8] This expectation is realized by the analyzing power results presented in Fig. 1.

The most significant feature of $A_y(\theta)$ for the 5⁻ T=0 state is the zero near 43°. This zero is associated with a change in sign of the imaginary part of the spin-independent central component of the two-nucleon t-matrix interaction which occurs at a momentum transfer of q ~ 1.8 fm⁻¹. This change in sign also produces a minimum in the central contribution to the 5⁻ cross section, but it is completely masked by the large spin-orbit contribution.
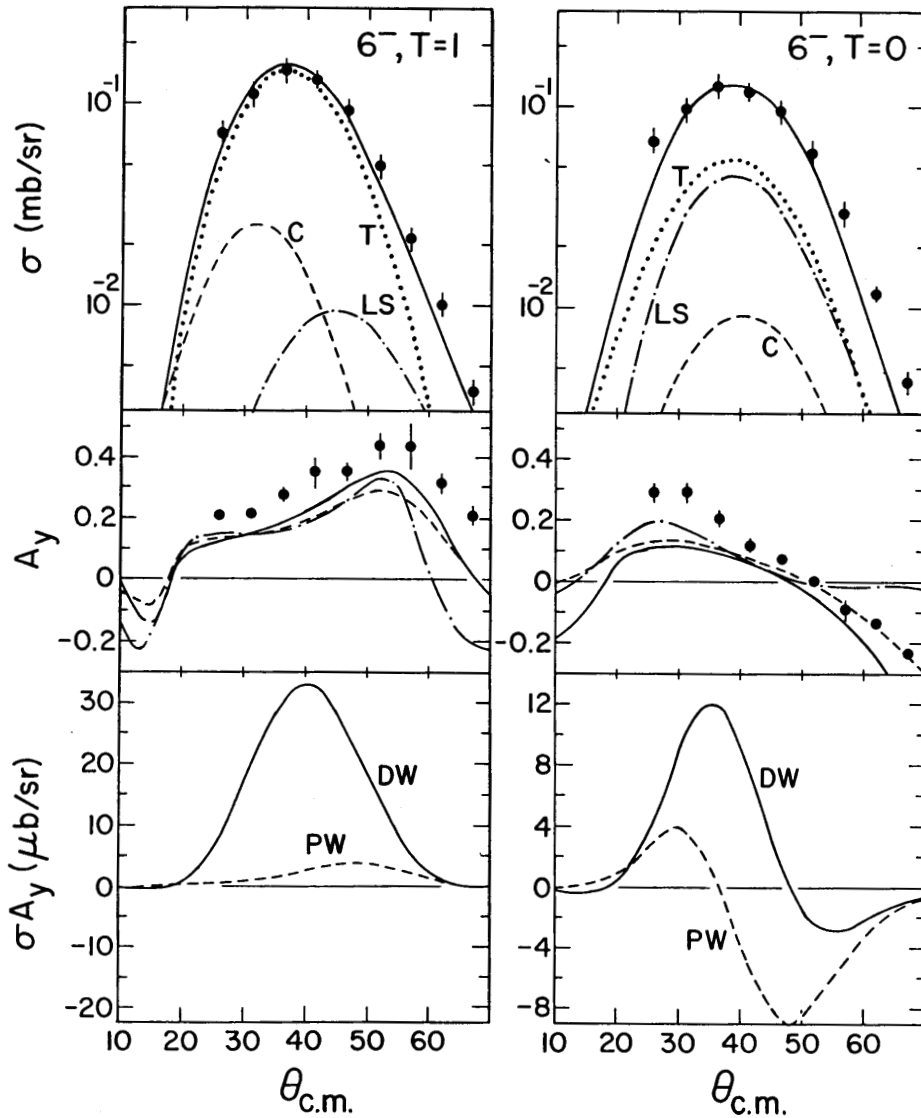
Figure 2. Results of cross section and analyzing power measurements, and calculations, for the 6⁻states of ²⁸Si (T=1 at 14.35 MeV, T=0 at 11.58 MeV). Full curves show the results of the full DWIA calculations. Results calculated for the differential cross sections, based on an $f_{7/2}d_{5/2}^{-1}$ transition starting with a filled $d_{5/2}$ shell, have been multiplied by 0.29 (for the T=1 state—the corresponding factor found in (e,e') was 0.33) and 0.10 (for the T=0 state). The dashed curves in the A_y plots show results obtained with a more recently fitted optical model potential (and the original t-matrix), while the dash-dot curves show results from the complete t-matrix of ref. 8 and the new optical potential. The importance of distortions for the analyzing powers of these transitions is shown in the σA plots at the bottom.

To further emphasize that the analyzing power provides information not contained in the differential cross section, we have included in Fig. 1 the result of a DWIA calculation for the 5⁻ state that was made with an imaginary central interaction of zero range that has no sign change. It is clear that this interaction fails to describe the analyzing power even though an adequate description of the differential cross section is obtained. This is in contrast to measurements of $A_y(\theta)$ for collective states in the diffractive regime.[16] Referring to the $\sigma A_y(\theta)$ graphs in Fig. 1 where we have compared the theoretical PWIA and DWIA results, we note that the main effect of distortion is to reduce the values of $\sigma A_y(\theta)$ by about a factor of 2,

most of which occurs in σ alone.

The 6⁻, T=0 and T=1 excitations are unnatural-parity transitions of stretched character whose transition matrix elements are completely specified by the $f_{7/2}d_{5/2}^{-1}$ particle-hole configuration.[13] For an unnatural-parity transition to a stretched state, $A_y(\theta)$ is given in the PWIA by[15]

$$A_y(\theta) = \frac{2t_R^{LS}(t_I^C + t_I^{T\beta}) - 2t_I^{LS}(t_R^C + t_R^{T\beta})}{|t^C + t^{T\alpha}|^2 + |t^{LS}|^2 + |t^C t^{T\beta}|^2 + 2J/(J+1)|t^C + t^{T\gamma}|^2}$$

where $t^{T\alpha}$, $t^{T\beta}$, and $t^{T\gamma}$ are three different linear combinations of the direct and exchange tensor terms and t^C now refers to the spin-dependent central force. This expression clearly shows that $A_y(\theta)$ contains information about the interference between the spin-orbit term and both the tensor and central terms of the effective interaction. The differential cross section contains information concerning interference only between the central and tensor terms in the interaction. In the PWIA we expect small analyzing powers, since t_I^C, t_I^T, and t_I^{LS} are all small. (The latter two have actually been neglected in the present calculations). The observed 6⁻ analyzing powers are, in fact, reasonably large and well described by the DWIA results shown in Fig. 2. As the graphs of $\sigma A_y(\theta)$ indicate, distortion is an important consideration here and the 6⁻ DWIA results exceed the PWIA results. This can be understood as a contribution to $A_y(\theta)$ from a term in $|t_R^T|^2$ which is allowed in the presence of spin-orbit distortion.[17] This term plays an important role because t_R^T is very large (see Fig. 2) and makes no contribution to the $A_y(\theta)$ in PWIA.

We have also performed calculations in which the tensor interaction was assumed to be strong and purely imaginary. In this case the DWIA results were found to be much closer to the PWIA results and substantial negative analyzing powers were predicted. This is incompatible with experimental data. We have repeated the calculations with the recent two-nucleon t-matrix of Ref. 8 (which includes the small imaginary parts of the tensor and spin-orbit interactions), and with a new set of optical-model parameters determined from the simultaneous fit to the elastic scattering cross sections and to new elastic analyzing power data from this experiment. The results are displayed as the dash-dot curves in the $A_y(\theta)$ plots in Fig. 2. The dashed curves were calculated with the new optical potential and the original t-matrix. The differences between the new calculations and the original solid curves are seen to be small in the region of interest.

In summary, new analyzing power data for the excitation of the 5⁻,T=0 (9.70 MeV) natural-parity level in ^{28}Si provide striking verification of the existence of a sign change near q ~ 1.8 fm⁻¹ in the imaginary part of the spin-independent central component of the effective nucleon-nucleon interaction. This sign change can be associated with the short-range repulsion in the nucleon-nucleon force. Corresponding data for the 6⁻, T=0 (11.58 MeV) and 6⁻, T=1 (14.35 MeV) unnatural-parity levels suggest that the phase of the high momentum components of the tensor part of the effective interaction is largely real. This is consistent with the free t-matrix and is expected from π and ρ-exchange contributions.[18] The overall success of the DWIA in describing the present analyzing power data suggests even more strongly than previous cross section results,[3-6] that competing reaction mechanisms are relatively unimportant for the excitation of high-spin states in this energy range.

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ELASTIC AND INELASTIC SCATTERING OF POLARIZED PROTONS
BY ⁴⁸Ca AT HIGH MOMENTUM TRANSFER

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Elastic and inelastic scattering of polarized protons on ⁴⁸Ca were studied at an incident energy of 160 MeV using the QDDM magnetic spectrograph. Data were taken in the fast spin-flip mode, with typical spin up and down polarizations of about 68 percent. About 35 peaks, representing excitations up to ≈10 MeV, have been analyzed. Portions of spectra obtained for a forward angle and a backward angle are shown in Figs. 1 and 2. Cross section and analyzing power angular distributions are shown in Fig. 3. Of special interest is the 1⁺ state at 10.2 MeV excitation which might be expected to show evidence of precritical phenomena. Data for this state are shown in Fig. 4.