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Inelastic scattering of polarized protons to unnatural parity states in ^{40}Ca and ^{28}Si

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Cross sections and analyzing powers leading to unnatural parity states of 2^-, T=0 (6.025 and 6.75 MeV), 2^-, T=1 (8.42 MeV) in ^{40}Ca and 6^-, T=0 (11.58 MeV) and 6^-, T=1 (14.36 MeV) in ^{28}Si were measured at 65 MeV. These states are pair states of different isospin with same spin-parity. The analyzing powers for a pair of T=0 and T=1 excitations in ^{40}Ca show an isospin dependence and those in ^{28}Si do not show. The measured angular distributions were compared with microscopic DWBA calculations using two sets of the effective nucleon-nucleon interaction. In the case when the tensor interaction is essential in reproducing the cross section data, good agreements between the calculations and the data for the analyzing powers are obtained. The trends are common to the calculations using two sets of the interaction.

KEY WORDS: ^{40}Ca, ^{28}Si$(\vec{p}, p')$ Reactions/ Unnatural parity states of 2^-, 6^-/ Microscopic DWBA calculations/ Tensor interaction/

I. INTRODUCTION

Spin-isospin modes of nuclear excitations are important for studying nuclear excitation process and effective nucleon-nucleon interaction. Such excitation modes have been extensively studied in proton inelastic scattering. Until now there have been many attempts to analyze cross section data in (p, p') inelastic scattering using a microscopic model, but there are not so many data of analyzing powers.[1~3] The analyzing powers of the scatterings in combination with the cross sections are expected to reduce an ambiguity of the analyses. We intend to investigate spin-isospin excitation modes in the polarized proton scattering to pairs of unnatural parity states of different isospin (T=0 and T=1) with same spin and parity.

In the present paper, we report the high resolution measurements of cross sections and analyzing powers leading to the 2^- (T=0 and T=1) states in ^{40}Ca, 6^- (T=0 and T=1) states in ^{28}Si and 6^- state (T=1) in ^{24}Mg in the (p, p') inelastic scattering at 65 MeV. The 2^- (T=0 and T=1) states in ^{40}Ca can be considered to be mainly the $(1f_{7/2})(1d_{3/2})^{-1}$ particle-hole configuration[4~6] and the 6^- (T=0 and T=1) states are predominantly specifed by the $(1f_{7/2})(1d_{5/2})^{-1}$ particle-hole configuration.[7]

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Analyzing powers and cross sections were measured for 6^- (T=0 and T=1) states in ^{28}Si at 135 MeV.[1,8,9] The analyzing powers for the two 6^- states were well reproduced by DWIA calculations with an effective interaction[1]. These data gave new information on the central and the tensor components of the effective nucleon-nucleon interaction and also showed that the effective interaction used in microscopic calculations of inelastic scattering has a strong tensor component. On the other hand, though cross sections for (p, p') excitation of the unnatural parity states in ^{40}Ca were measured at various energies less than 65 MeV and were analyzed by the microscopic calculations, the sensitivity to the tensor component was little discussed.[10~12] Moreover, in the energy region lower than 100 MeV, this component may be usually overwhelmed by the stronger central parts of the interaction.[13] We consider that analyzing powers are useful in studying the contribution from each component in the effective interaction to the (p, p') scattering.

II. EXPERIMENTAL PROCEDURES

The experiment was performed with 65 MeV polarized protons. The polarized protons from the atomic-beam-type polarized ion source[14] were accelerated by the AVF cyclotron of RCNP, Osaka University. The ^{12}C-polarimeter which monitored continuously the polarization of the incident beam was placed 100 cm upstream the target chamber.[15] The polarimeter target was a 2.5 mg/cm^2-polyethylene foil.

The scattered protons were analyzed by means of the magnetic spectrograph RAIDEN[16] and were detected by the 1.5 m focal plane detectors which consisted of a position sensitive resistive-wire proportioal counter followed by dual proportional counters (ΔE_1 and ΔE_2) and a plastic detector(E).[17] They were operated in a four-fold coincident mode and the particle identification was performed by using the ΔE_1, ΔE_2 and E signals. The overall energy resolution in the experiment was typically 35 keV.

III. EXPERIMENTAL RESULTS

The angular distributions of cross sections and analyzing powers are shown in Figs. 1 to 4. The error quoted in the figures is overall one which comes from the statistical error and the uncertainty caused from background subtraction. The uncertainty in the masured beam polarization for the analyzing powers was negligible in the experiment. The difference of the angular distributions of cross sections between each pair of T=0 and T=1 states with same spin-parity is not so pronounced. The most interesting features of the data are following.

(1) The angular distributions of analyzing powers leading to a pair of T=0 and T=1 states with same spin-parity in ^{40}Ca show the strong isospin dependence as shown in Fig. 1. This is quite similar to the case of 1^+ pair of ^{12}C in which the angular distributions of analyzing powers showed the out-of-phase pattern.[3]

(2) On the other hand, the shapes of the angular distributions of the analyzing powers leading to the 6^- pair of T=0 and T=1 in ^{28}Si are similar to each other as shown in Fig. 3. This is different from the cases of 2^- states in ^{40}Ca and 1^+ states in ^{12}C. The

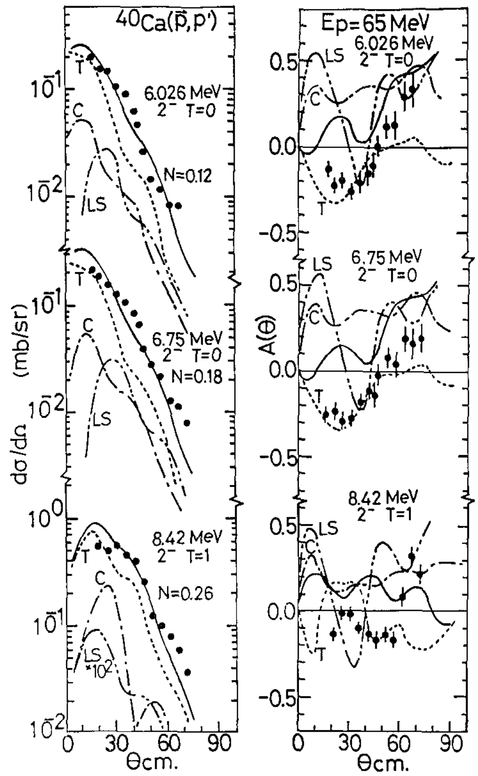

Fig. 1. Angular distributions of cross sections and analyzing powers for 2^- (T=0) and 2^- (T=1) states in ^{40}Ca. The curves are the DWBA calculations which are calculated with TYPE-I (M3Y) interaction. The solid curves represent the calculations including all component in the interaction. C, T and LS mean the calculations with central alone, tensor alone and spin-orbit component alone, respectively. N is a normalization factor.

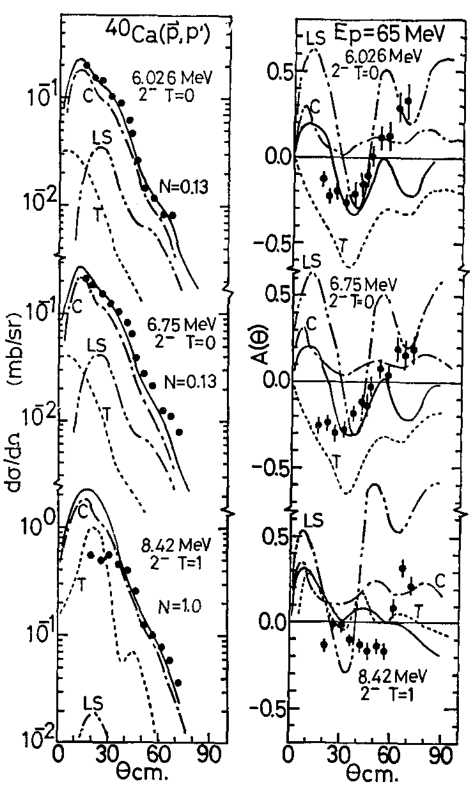

Fig. 2. Angular distributions of cross sections and analyzing powers for 2^- (T=0) and 2^- (T=1) states in ^{40}Ca. The curves are the DWBA calculations which are calculated with TYPE-II (Petrovich *et al.*). See also the caption for Fig. 1.

angular distributions of cross sections and analyzing powers to 6^- state (T=1) in ^{24}Mg are very similar to 6^- state (T=1) in ^{28}Si. These states can be considered to have same configuration and to be excited through same process.

IV. DWBA ANALYSIS AND DISCUSSION

The cross sections and analyzing powers for the unnatural parity states were calculated by using the code DWBA74[18] which includes both the one-step direct and the knock-out exchange processes. In the calculations, we used the wave functions calculated by Perez[4] for 2^- states in ^{40}Ca but we dropped very small admixing terms. The configuration

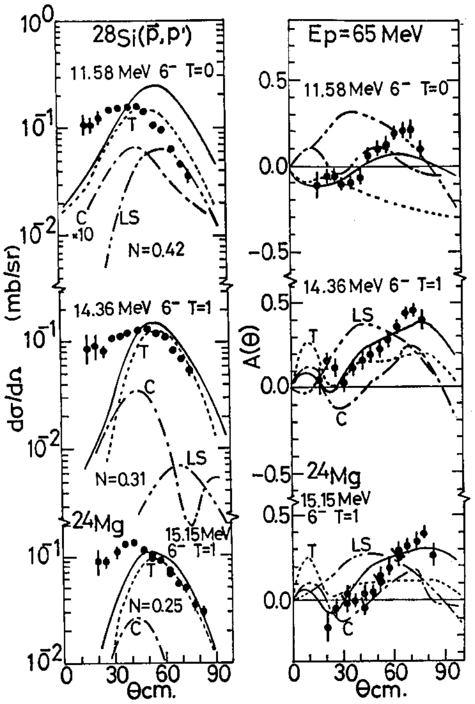

Fig. 3. Angular distributions of cross sections and analyzing powers for 6⁻ (T=0) and 6⁻ (T=1) states in ^{28}Si and 6⁻ (T=1) state in ^{24}Mg. The curves are the DWBA calculations which are calculated with TYPE-I interaction. See also the caption for Fig. 1.

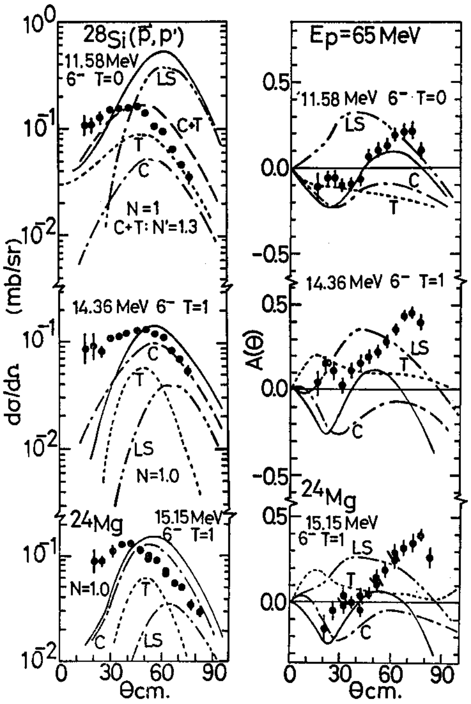

Fig. 4. Angular distributions of cross sections and analyzing powers for 6⁻ (T=0) and 6⁻ (T=1) states in ^{28}Si and 6⁻ (T=1) state in ^{24}Mg. The curves are the DWBA calculations which are calculated with TYPE-II interaction. N′ is a normalization factor for the calculation with a central plus tensor component. See also the caption for Fig. 1.

for the 6⁻ states in ^{28}Si was assumed to be $(1f_{7/2})(1d_{5/2})^{-1}$ simple particle-hole configuration.[7~9] The proton optical potential parameters were those derived by Sakaguchi *et al.*[19] These parameters give the best fits to both the polarization and cross section data for elastic scatterings at 65 MeV.

The differential cross sections and analyzing powers were calculated for two sets of the two body force, which are M3Y[20] force (designated here as TYPE-I) and the effective nucleon-nucleon interaction (TYPE-II) used by Petrovich *et al.*,[21] respectively.

Comparisons between calculations with TYPE-I and the experiments are shown in Figs. 1 and 3. Those between calculations with TYPE-II and the experiment are shown in Figs. 2 and 4. In these figures, contributions from each component of the force are also shown, where solid curves show the calculations with all components of central, tensor and spin-orbit forces and C, T and LS mean the calculations with the central force alone, the tensor force alone and the spin-orbit force alone, respectively. N is a normalization factor to be multiplied to the theoretical cross section. This factor may be attributed to an incompleteness of the wave functions of the interactions.

We may derive the following feature in the present (p, p') scattering from a comparison between the data and the calculations by using the wave functions described above and both interactions of M3Y[20] (TYPE-I) and Petrovich *et al.*[21] (TYPE-II). When the shapes of the cross section data can be well described mainly by the central component in the interaction, the experimental analyzing powers can not be reproduced by the calculations. On the other hand, when the shapes of the cross sections can be described well either by the tensor component alone or by the tensor plus central component, the theoretical results for the analyzing powers give acceptable agreements with the experiments. The calculations without the tensor component in the interaction do not give a good fit to the data of both cross sections and analyzing powers simultaneously. The spin-orbit force makes generally a small contribution to the cross section except the calculations with the TYPE-II interaction for the 6^-, T=0 state in ^{28}Si. For these excitations, an agreement between the theoretical and experimental cross sections is worsened by including the spin-orbit component. However the contribution from the spin-orbit component brings a good agreement between the theoretical and the experimental analyzing powers for these excitations. In the case when the central interaction is essential for reproduction of the cross section data, any agreement can not be obtained in the analyzing powers. The fact is common to the calculations using two sets of the interaction, though all data can not be explained systematically by the calculation using either TYPE-I or TYPE-II interaction. It is important to emphasize that the strength of the tensor interaction is essential for producing simultaneously a good agreement between the calculation and the data for both cross sections and analyzing powers in the gross feature.

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