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Pion-induced double charge exchange on ^{12}C, ^{24}Mg, ^{32}S, and ^{40}Ca

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Angular distributions for pion-induced double-charge-exchange (DCX) reaction have been measured at 164 MeV on the T=0 target nuclei ^{12}C, ^{24}Mg, ^{32}S and ^{40}Ca. The data are compared to calculations using the Δ-nucleon interaction model with realistic wave functions and πNN and ρNN form factors deduced from fits to previously published DCX data on ^{16}O. The calculations reproduce the general shape of the angular distributions and the absolute magnitude of the cross sections to within a factor of two.

I. INTRODUCTION

There is a large body of experimental data for the pion double-charge-exchange (DCX) reaction[1] on nuclei throughout the periodic table. These data consist mainly of forward-angle (5°) excitation functions measured for a range of nuclei. In a few cases angular distributions have also been measured. Measurements have been made for both analog transitions for which the initial and final states are related by isospin symmetry, the so-called double isobaric analog transitions (DIAT), and for nonanalog transitions for which the initial and final states are not related by isospin symmetry. The two sets of data show very different A dependences. The DIAT data have cross sections that vary as $A^{-10/3}$, indicative of a two-step mechanism. The $A^{-4/3}$ dependence of the nonanalog transitions is similar to that observed in pion single charge exchange (SCX),[2] which can be explained by a one-step mechanism.

Johnson and collaborators[3-6] have developed a model for the nonanalog component of the DCX cross section; they propose that the Δ-nucleon interaction (DINT) mechanism is responsible for the nonanalog ground-state transitions. In this mechanism, the incoming π^+ interacts with a neutron to form a Δ^+. The Δ^+ charge exchanges by a virtual π or ρ with another neutron to form a Δ^0. The resulting Δ^0 then decays into a proton and a π^- which is detected. This model[3-6] gives a good explanation of the energy, and mass dependence of the nonanalog g.s.→g.s., $0^+ \rightarrow 0^+$ transitions, provided realistic wave functions are used. An alternative calculation has been put forward by Ching *et al.*;[7] they use an eikonal model to calculate the nonanalog DCX cross section on the assumption that it is due to a single π-Δ charge exchange, analogous to the π-N single charge exchange used to explain the pion single-charge-exchange measurements. These calculations give a good representation of the shape of the forward-angle portion of the ^{12}C and ^{40}Ca angular distributions, but if normalized to the small-angle data they consistently overestimate the magnitude of the cross section beyond the first minimum. This is because the approximations they use in their eikonal diffraction calculation are invalid at larger angles.

To provide further data to test the predictions of nonanalog DCX models, in particular the DINT model, the partial angular distributions[8] for ^{12}C and ^{40}Ca used in Ref. 5 have been completed and new measurements on

^{24}Mg and ^{32}S have been made. These self-conjugate target nuclei are ideal for testing the predictions of the DINT model because they have $T = 0$ and the DIAT is forbidden by isospin arguments. Consequently, this removes any possible interference between the analog and the nonanalog transitions. Also, reliable shell-model wave functions[9–12] are available for these nuclei, and uncertainties due to nuclear-structure effects can be largely removed from the calculations.

II. EXPERIMENT

Data were collected using the DCX setup[13] of the Energetic Pion Channel and Spectrometer facility[14] (EPICS) at the Clinton P. Anderson Meson Physics Facility (LAMPF), Los Alamos. EPICS consists of a momentum-dispersing pion channel and a high-resolution spectrometer. Position-sensitive delay-line read-out drift chambers measure the particle positions and angles of the ejectile, before and after momentum analysis, allowing on-line reconstruction of the scattering angle and incident pion momentum and calculation of the scattered pion momentum. The Q value for the interaction can thus be determined and stored in a pion energy-loss spectrum.

Data were taken at 5° intervals for laboratory scattering angles between 5° and 40° using an incident pion energy, $T_\pi = 164$ MeV. The momentum spread of the channel was set to $\pm 1\%$ and the scattering angle acceptance to 3°. Electrons were eliminated by time-of-flight measurements and by a freon-gas Cherenkov detector in the focal plane. A set of veto scintillators separated by graphite wedges in the focal plane was used to reject muons. These were fine tuned by use of a variable-thickness aluminum absorber in front of the first scintillator.

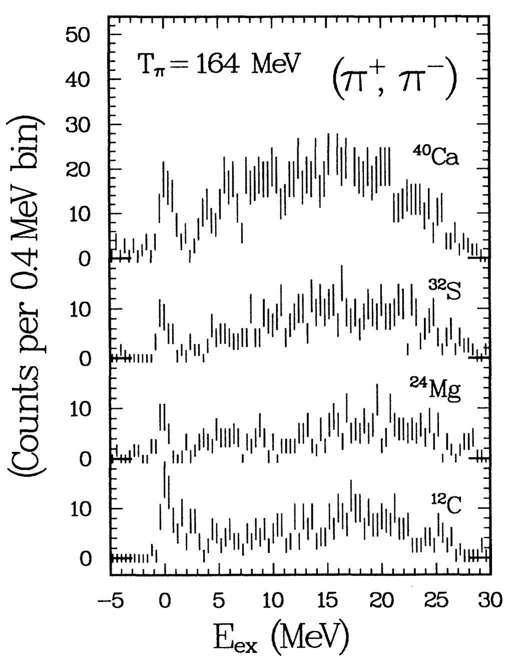

FIG. 1. Excitation energy spectra for the (π^+, π^-) reaction on ^{12}C, ^{24}Mg, ^{32}S, and ^{40}Ca at 164 MeV.

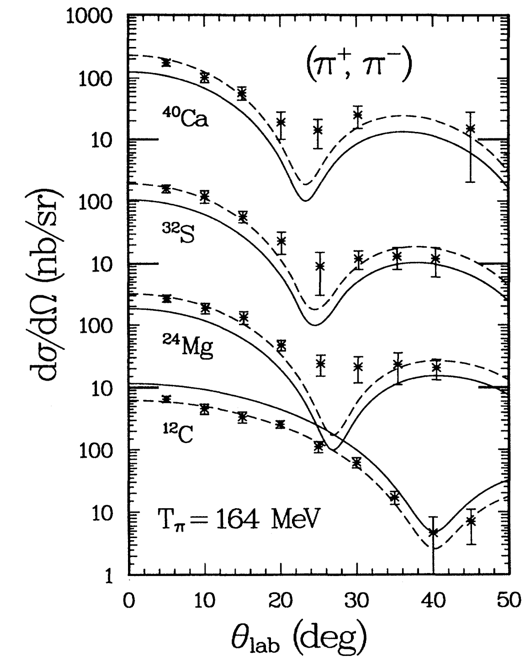

FIG. 2. Experimental angular distributions and DINT calculations for the (π^+, π^-) reaction on ^{12}C, ^{24}Mg, ^{32}S, and ^{40}Ca at 164 MeV. The solid curves are the DINT calculations (see text), and the dashed curves are the same calculations but renormalized to give the best fit to the forward-angle data.

Figure 1 shows excitation energy spectra for ^{12}C, ^{24}Mg, ^{32}S, and ^{40}Ca summed over several of the angles measured. The spectra show the peak due to the ground-state transition and part of the continuum. These spectra have not been corrected for the variation of the acceptance of the spectrometer along the focal plane. To remove any problems associated with this variation it was arranged that the peak due to the ground-state transition was at the same position in the focal plane for all measurements. Summed spectra of this type were used as a guide to the limits of integration for the poorer-statistics spectra taken at the individual angles. The small cross section for the double-charge-exchange reaction requires the use of thick targets, so natural materials were used. The areal density and isotopic purity of the targets used are given in Table I. The data obtained for the ground state were normalized by comparing the yields from π^+ scattering from hydrogen to the π–nucleon cross sections calculated using the Coulomb-corrected phase shifts of

TABLE I. Areal density and isotopic purity of the targets.

Target	Areal density (g/cm^2)	Isotopic purity (%)
^{12}C	1.09	98.89
^{24}Mg	1.43	78.99
^{32}S	2.00	95.02
^{40}Ca	2.30	98.94

Rowe *et al.*[15] The uncertainty in the overall normalization of the angular distributions is ±10%. The angular distributions obtained for the four targets are shown in Fig. 2.

III. RESULTS AND DISCUSSION

The magnitude of the 5° cross section determined in the present work agrees extremely well with previously measured[8] values for all four targets. The additional data taken for ^{12}C and ^{40}Ca angular distributions are also in very good agreement with the previous data.[8]

Calculations have been performed using the DINT model for the DCX reaction. These calculations use the model of the Δ–nucleon force as explained in Refs. 3 and 4 and the realistic wave functions and the reaction mechanism given by model III of Ref. 5. The results of the present calculations are shown as solid curves in Fig. 2. It can be seen that the calculations generally reproduce the shapes of all four experimental angular distributions and fit the absolute magnitude of the cross sections to within a factor of 2. The dashed curves shown in Fig. 2 have been normalized to give the best fit to the data and the normalization factors required for ^{12}C, ^{24}Mg, ^{32}S, and ^{40}Ca are respectively 0.54, 1.74, 1.80, and 1.84. The closeness of the normalization factors to unity is an indication of the overall reliability of the wave functions used in the calculations. The variation between nuclei of these normalization factors could be due to the exclusion of the non-0^+ components of the wave function in the calculations.

In their recent paper Wirzba *et al.*[6] have investigated both the DINT and sequential mechanisms. Their calculations indicate that at resonance energies the cross section for the sequential mechanism is only 0.2 times as large as that due to the DINT mechanism but has a similar angular distribution. Thus, the inclusion of a sequential mechanism will increase the overall cross section by a small amount but is not responsible for the discrepancy between the experimental data and the DINT calculations reported here.

In conclusion, we have measured angular distributions for pion double-charge exchange on several $T=0$ targets leading to the ground state of the residual nucleus. All the data are qualitatively reproduced by DINT calculations, but the theory, which has parameters adjusted to fit ^{16}O data, does not give the correct absolute magnitude for the data, presented here. It does not seem that a sequential mechanism is important for the nonanalog transitions reported.

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