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Target mass dependence of isotensor double charge exchange: Evidence for deltas in nuclei

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Measurements of forward-angle cross sections for double charge exchange on ^{16}O, ^{28}Si, and ^{40}Ca at 164 MeV incident pion energy suggest an $A^{-4/3}$ dependence for the cross section. This A dependence is shown to provide evidence for Δ components in the nuclear wave function.

NUCLEAR REACTIONS ^{16}O(π^+,π^-), ^{28}Si(π^+,π^-), ^{40}Ca(π^+,π^-); $E_\pi = 164$ MeV; measured $\sigma(5°)$, and mass excesses for ^{28}S and ^{40}Ti, found $A^{-4/3}$ dependence for cross section.

Conclusions from previously measured cross sections[1] for pion-induced double charge exchange (DCX) are as follows:

(1) At energies near 160 MeV, differential cross sections for $T=0$ targets are comparable to those for $T=1$ targets, e.g., at 5° and 164 MeV, $[d\sigma/d\Omega(^{18}\text{O})]/[d\sigma/d\Omega(^{16}\text{O})] \simeq 2.0$; and at 5° and 141 MeV, $[d\sigma/d\Omega(^{26}\text{Mg})]/[d\sigma/d\Omega(^{24}\text{Mg})] \simeq 1.1$. These results are surprising because in the simplest models of DCX the former are forbidden.

(2) Individual cross sections and $[d\sigma/d\Omega(T=1)]/[d\sigma/d\Omega(T=0)]$ cross-section ratios are strongly dependent on bombarding pion energy.

(3) Angular distributions for the allowed cases ($T \geq 1$ targets) are diffractive at a bombarding energy of 292 MeV, but are not simply diffractive at 164 MeV.

An empirical model[2] has been introduced to account for these features. The model contains two amplitudes—one is the usual allowed double isobaric analog transition (DIAT) amplitude connecting double analog states, and the other is a "forbidden" isotensor (non-DIAT) amplitude. The latter is taken to be identically zero in virtually all other calculations[3] of double charge exchange.

In Ref. 2, the DIAT amplitude for ^{18}O was taken from a calculation of Miller and Spencer,[3,4] and the non-DIAT amplitude was taken from an experiment for DCX on ^{16}O. In the model, the ^{18}O amplitude is then a sum of the DIAT and non-DIAT terms, with an energy-dependent relative phase between them, each amplitude entering with unit multiplicative factor. A fit to the 5° excitation function data for ^{18}O resulted in a smoothly varying phase that starts out near zero at low pion energies and increases to approximately 90° near 170 MeV—very similar to the behavior which one would expect for a resonant process.

In most models[3-5] of DIAT, the DCX cross section scales approximately as $(N-Z)(N-Z-1)A^{-10/3}$. In order to better understand the non-DIAT process, we have measured (π^+, π^-) cross sections at a laboratory angle of 5° and a bombarding energy of 164 MeV for targets of ^{16}O, ^{28}Si, and ^{40}Ca. In every case it is the ground-state transition that is of interest.

The experiment was performed at EPICS[6] (energetic pion channel and spectrometer) at LAMPF (Clinton P. Anderson Meson Physics Facility at Los Alamos), using the standard DCX setup[2]; with the addition of focal-plane muon rejection. Targets were natural Ca of areal density 1.3 g/cm^2 and natural SiO$_2$ of 1.4 g/cm^2. The ^{40}Ca spectrum is displayed in Fig. 1.

Byproducts of the present measurements are values of the masses of ^{28}S and ^{40}Ti. Our measured mass excesses are 4.13 ±0.16 and −8.79 ±0.16 MeV for ^{28}S and ^{40}Ti, respectively. The large uncertainties are primarily statistical, and reflect the poor energy resolution obtained from the thick targets—the emphasis was on cross-section determinations. These mass excesses are compared with predictions in Table I.

Cross sections from the present work are plotted versus target mass (A) in Fig. 2, along with previous 180-MeV cross sections for ^{12}C, ^{16}O, ^{24}Mg, and ^{32}S from an earlier work.[7] The curves are for $A^{-4/3}$ falloff. We find that these non-DIAT cross sections fall much more slowly with A ($\approx A^{-4/3}$) than do cross sections for DIAT ($\approx A^{-10/3}$). One consequence of this measurement is that the experimental ^{40}Ca cross section is significantly larger than the predicted DIAT cross section for ^{42}Ca, so that if our earlier two-amplitude model of DCX is correct, we would expect DCX on ^{42}Ca to be dominated by the non-DIAT process.

A calculation by Lee, Kurath, and Zeidman[8] has addressed the question of the process for non-DIAT DCX. Specifically, they calculate the $[d\sigma/d\Omega(^{16}\mathrm{O})]/[d\sigma/d\Omega(^{18}\mathrm{O})]$ ratio by including particle-hole components in initial- and final-state wave functions. The magnitudes of these core-excited components sensitively determine the size of the cross section. Their model can explain the $[d\sigma/d\Omega(^{16}\mathrm{O})]/[d\sigma/d\Omega(^{18}\mathrm{O})]$ ratio at 164 MeV, but not its energy dependence nor the nondiffractive ^{18}O angular distribution. Also, their model, if applied to other $T=0$ nuclei, may not produce a smooth A dependence because of its extreme sensitivity to the details of core excitation.

TABLE I. Mass excesses.

Nucleus	Predicted[a] (MeV)	Measured (MeV)
^{28}S	4.120 ± 0.021	4.134 ± 0.160
^{40}Ti	− 9.150 ± 0.090	− 8.792 ± 0.160

[a] IMME (isobaric multiplet mass equation) prediction, P. M. Endt and C. van der Leun, Nucl. Phys. A310, 1 (1978).

In Fig. 3, we have renormalized upward all the 180-MeV data so as to compare the A dependence of the full data set. It can be seen that a curve falling as $A^{-4/3}$ gives a reasonable account of the data. What is required is a reaction mechanism that will produce such an A dependence. Since most cross sections increase with A (the bigger the target, the larger the cross section), an $A^{-4/3}$ falloff must result from a process in which the basic matrix element decreases with A. But the decrease must be slower than that

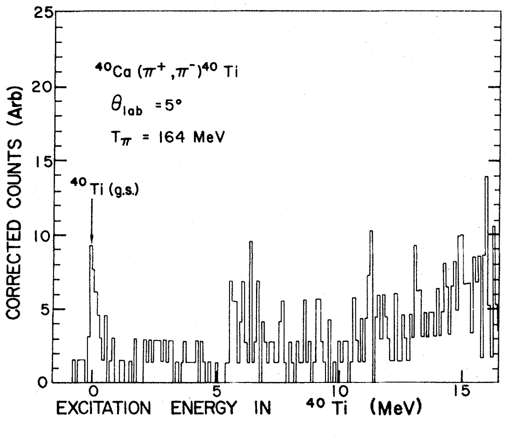

FIG. 1. Spectrum of the (π^+, π^-) reaction on a target of ^{40}Ca at an incident pion energy of 164 MeV and laboratory angle at 5°.

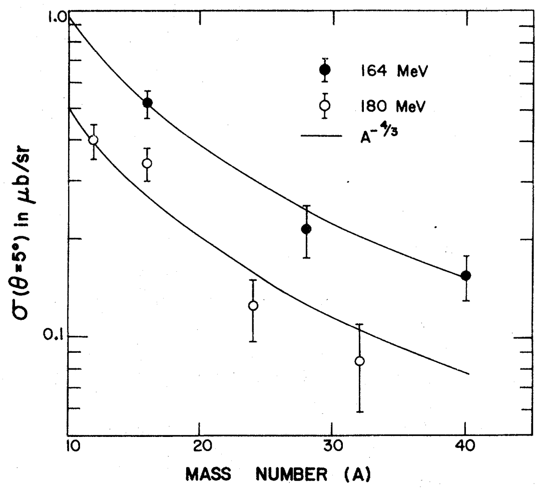

FIG. 2. Cross sections at 5° and 164 MeV (closed circles) and 180 MeV (open circles) for (π^+, π^-) reactions on $T=0$ targets, plotted vs target mass (A). The curves represent an $A^{-4/3}$ dependence.

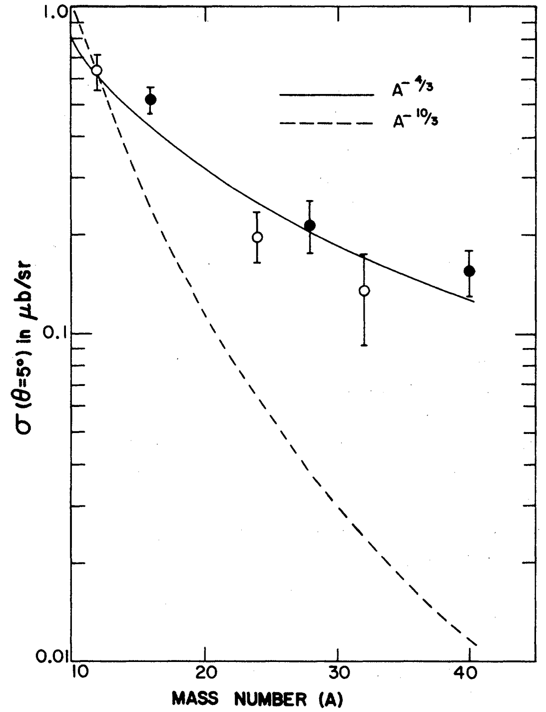

FIG. 3. The data of Fig. 2, with the 180-MeV points uniformly shifted up. Solid curve falls as $A^{-4/3}$, dashed curve as $A^{-10/3}$.

for DIAT, for which the cross section decreases as $A^{-10/3}$. This $A^{-10/3}$ dependence is purely "geometrical" and arises because the DIAT process is *two-step*, each step of which has an amplitude proportional to A^{-1} giving an overall A^{-4} which then multiplies a "fundamental" cross section of $R^2 \propto A^{2/3}$.

Thus, one possibility for obtaining an $A^{-4/3}$ dependence would be a *one-step* process whose amplitude is proportional to A^{-1}. Such a process is provided by single-step DCX to a final-state wave function component that contains a delta, Δ^{++}, if the mixing element giving rise to the Δ component varies as A^{-1}, as appears likely.[9] Such a mechanism is depicted in Fig. 4. In the eikonal model the reaction amplitude should vary as

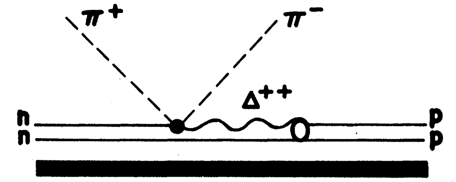

FIG. 4. A one-step DCS process to a final state containing a Δ^{++}. The solid bar below represents the noninteracting nucleons in the nucleus.

$$f(k,q) = \beta k R a \frac{f(\pi^+ n \to \pi^- \Delta^{++})}{f(\pi^+ N \to \pi^+ N)} J_0(qR) \ ,$$

where

$$\beta \simeq \frac{\langle \Delta^{++} n^{-1} | H | p^2 n^{-2} \rangle}{300 \text{ MeV}}$$

is the amplitude of Δ component in the dominantly p^2n^{-2} ground state of the final nucleus. A crude estimate of the mixing matrix element can be made with this model. The ratio of amplitudes, $f(\pi^+ n \to \pi^- \Delta^{++})/f(\pi^+ N \to \pi^+ N)$, is assumed to be unity. Taking values for the strong absorption radius and diffuseness for ^{18}O from Johnson[5] of 3.50 and 1.0 fm, and using these for ^{16}O, we find $\beta \simeq 0.024/A$, and the matrix element, $\langle \Delta^{++} n^{-1} | H | p^2 n^{-2} \rangle \simeq 7/A$ MeV. This is smaller than most previously suggested values of β.

If the above model is correct, pion DCX reactions provide a *direct* method of measuring Δ admixtures in low-lying nuclear states. It may be that other mechanisms could give rise to $A^{-4/3}$ dependence, but at present, there is *no* acceptable model for DCX on $T = 0$ targets. It is hoped that the present work will stimulate some theoretical interest in this problem.

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