Interference effects in pion double charge exchange

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Pion double charge exchange (π^+,π^-) has been measured using targets of ^{16}O and ^{18}O from 80 to 292 MeV at a laboratory angle of 5°. The magnitude and energy dependence of the cross section for the double-analog transition is qualitatively described in terms of a direct double-analog amplitude and a two-step nonanalog amplitude.

[NUCLEAR REACTIONS ^{16}O$(\pi^+,\pi^-)^{16}$Ne(g.s.) and ^{18}O$(\pi^+,\pi^-)^{18}$Ne(g.s.); $\theta=5°$, $E_\pi=80$ to 292 MeV, deduced two amplitude explanation for cross-section variation.]

Perhaps the most perplexing result to emerge from double-charge-exchange (DCX) measurements with the (π^+,π^-) reaction is the observation[1,2] near the (3,3) pion-nucleon resonance that cross sections for the $T=0$ targets (^{16}O and ^{24}Mg) are almost as large as those for $T=1$ targets (^{18}O and ^{26}Mg). Of course, only the latter can proceed by the usual DCX mechanism[3,4] connecting the double isobaric analog state (DIAS) to the ground state (i.e., parent state) in the target. It would thus appear that some additional process is contributing to DCX and that it is not negligible compared with the DIAS transition.

An additional puzzling feature of the data is the structure in the excitation function[5] for ^{18}O$(\pi^+,\pi^-)^{18}$Ne(g.s.), which has been measured for pion kinetic energies from 80 to 292 MeV. At a laboratory angle of 5°, this cross section possesses a peak near 130 MeV, a dip near 170 MeV, and then a slow monotonic increase above that energy. This contrasts with calculations[4,6,7] for the DIAS transition alone, which predict a monotonic increase over the (3,3) resonance and beyond.

We report here on a measurement of an excitation function for ^{16}O$(\pi^+,\pi^-)^{16}$Ne(g.s.) and a very simple model that appears to account for the data. The ^{18}O$(\pi^+,\pi^-)^{18}$Ne(g.s.) data have been published previously.[5]

Data were collected on the energetic pion channel and spectrometer (EPICS) facility. A system for investigating DCX reactions, from 5° to 35° in the laboratory, has been incorporated[5] into the EPICS system. A circular bending magnet (in the horizontal plane) was positioned after the pion scattering target. This allowed the charge-exchanged pions of one polarity to be separated from the outgoing beam of the opposite polarity. Eliminating the unwanted pions significantly reduced the counting rate of the spectrometer entrance drift chambers. Targets chosen for the study were the isotopic pair ^{16}O and ^{18}O in the form of isotopically enriched ice of $\simeq 1.0$ g/cm^2 thick. The ^{16,18}O pair was chosen because of the many calculations performed for DCX on ^{18}O. Further experimental details are contained in Ref. 8.

The experimental excitation functions for ^{16,18}O$(\pi^+,\pi^-)^{16,18}$Ne(g.s.) are displayed in Fig. 1, along with the calculation of Miller and Spencer[7] for the ^{18}O$(\pi^+,\pi^-)^{18}$Ne(g.s.) DIAS transition. A number of observations are in order:

(1) The calculated curve appears to agree with the ^{18}O data, in both shape and magnitude, at the higher energies.

(2) The ^{16}O cross section is small at those higher energies.

(3) The ^{16}O cross section has a resonancelike structure with a peak near 160 MeV.

(4) The peak in the ^{16}O data roughly coincides with the dip in the ^{18}O data.

We believe the $^{18}O(\pi^+,\pi^-)^{18}Ne$(g.s.) amplitude is a sum of two terms: One is the usual double-isobaric-analog-transition (DIAT) amplitude, which leaves unchanged all quantum numbers (except t_z) of all nucleons, and has been referred to in the literature as a quasielastic amplitude[9]; the other, which we call non-DIAT, is the sum of all processes that can (without violating the Pauli principle) change any two neutrons into any two protons, e.g., $\nu(1d_{5/2})^2_{0+}\rightarrow\pi(2s_{1/2})^2_{0+}$, or $\nu(1p_{1/2})^2_{0+}\rightarrow\pi(1d_{5/2})^2_{0+}$, etc. For the present, we need only the forward-angle amplitudes as a function of energy. Let $B(E)$ represent DIAT and $A(E)$ non-DIAT. Then for $B(E)$ we can use the calculation of Miller and Spencer.[7] We propose to take $A(E)$ from experiment for $^{16}O(\pi^+,\pi^-)$ ^{16}Ne(g.s.). Because the pertinent non-DIAT routes for ^{16}O and ^{18}O are so similar, $A(E)$ for $^{18}O(\pi^+,\pi^-)^{18}Ne$(g.s.)

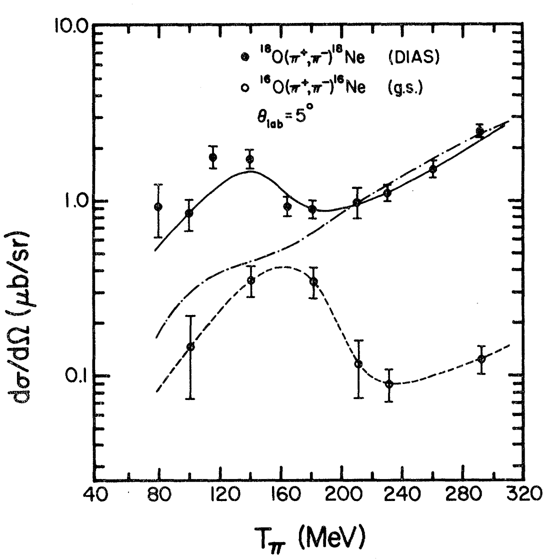

FIG. 1. Experimental points for $^{18}O(\pi^+,\pi^-)^{18}Ne$(g.s.) (closed circles) and $^{16}O(\pi^+,\pi^-)^{16}Ne$(g.s.) (open circles), measured at a laboratory angle of 5°, as a function of π^+ laboratory kinetic energy. The dot-dash curve is a calculation for the ^{18}O DIAS transition from Ref. 7. The solid curve is obtained from this curve and the smooth dashed curve through the $^{16}O(\pi^+,\pi^-)^{16}Ne$(g.s.) data as outlined in the text.

is approximately equal to $A(E)$ for $^{16}O(\pi^+,\pi^-)^{16}Ne$(g.s.). Rough estimates give a ratio beween 0.7 and 1.5, with reasonable assumptions about the relevant wave functions. In the simple model presented herein, we merely use a ratio of unity. If a specific model for non-DIAT ever becomes available, more detailed calculations can then be done. For the present we have

$$\sigma_{^{16}O}(E)=|A(E)|^2$$

and

$$\sigma_{^{18}O}(E)=|A(E)+B(E)|^2 ,$$

where $|B(E)|^2$ is the Miller-Spencer calculation.[7]

The amplitudes A, B are complex:

$$A=ae^{i\phi_a} \text{ and } B=be^{i\phi_b} ,$$

so that

$$\sigma(^{16}O)=a^2$$

and

$$\sigma(^{18}O)=|ae^{i\phi_a}+be^{i\phi_b}|^2$$
$$=a^2+b^2+2ab\cos|\phi_a-\phi_b| ,$$

where b^2 is the Miller-Spencer[7] cross section. We have obtained a rough fit to the data with only one parameter, $\Delta\phi=|\phi_a-\phi_b|$, which, however, is energy dependent. The solid curve in Fig. 1 is the result, with $\cos\Delta\phi$ smoothly varying from near 1 below 160 MeV to near 0 at and above 180 MeV. In general, the interference of the two amplitudes is constructive below the peak in the $^{16}O(\pi^+,\pi^-)^{16}Ne$(g.s.) data and destructive above that energy. However, for all points above the peak, the phase difference is only slightly larger than 90°, whereas below the peak the phase difference drops smoothly towards zero as the energy decreases. As simple as the present model is, it gives a good account of the data throughout the energy range.

Another puzzling feature of the $^{18}O(\pi^+,\pi^-)^{18}Ne$(g.s.) DCX data[5] is that at 164 MeV, the ^{18}Ne(g.s.) angular distribution has a minimum at a much smaller angle than would be expected from a diffractive model, whereas at 292 MeV, the minimum is at the correct angle. Within the present model, this effect is easily explained. At the higher energies, the non-DIAT amplitude makes a negligible contribution, but near 160 MeV it interferes strongly. Thus, even if the two angular distributions represented by A and B both have minima near the diffractive position, it is still possible for the strong interference to put the $^{18}O(\pi^+,\pi^-)^{18}Ne$(g.s.) minimum at a very different angle. Of course, a variety of interference effects can shift the angular-distribution minimum at 164 MeV. We offer a specific choice for the interfering amplitude: It is roughly the same amplitude as that giving rise to the $^{16}O(\pi^+,\pi^-)^{16}Ne$(g.s.) cross section. The smallness of the latter at 292 MeV leaves the position of the $^{18}Ne(\pi^+,\pi^-)^{18}Ne$(g.s.) minimum unchanged at that energy. It would be instructive to measure the ground-state angular distribution for $^{16}O(\pi^+,\pi^-)^{16}Ne$(g.s.), for which we expect a diffractive minimum. Knowledge of that data should help immensely in calibrating the nature of the non-DIAT contribution to DCX.

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