Elastic pion double charge exchange reactions

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Results of simple sequential model calculations are presented and compared with experimental data covering a wide variety of targets and energies. The model is fairly successful at higher energies (greater than about 200 MeV) but fails badly at lower energies.

[NUCLEAR REACTIONS (π^+, π^-) cross sections calculated and compared with experiment: 80 MeV $\leq E_\pi \leq$ 300 MeV.]

Recent measurements[1-4] of elastic double charge exchange (π^+, π^-) reactions have created considerable interest. In this process the initial and final nuclear wave functions have, within electromagnetic corrections, the same nuclear structure, so that the reaction has much of the simplicity of elastic scattering. However, because two units of charge are transferred, the reaction must proceed in a manner that involves two nucleons. Thus one has the opportunity of studying a variety of important processes involving a pion and two nucleons, including correlations,[5] true pion absorption [e.g., Fig. 1(a)], local field corrections [e.g., Fig. 1(b)], and antisymmetry effects [e.g., Fig. 1(c)]. However, in order to establish the presence of such interesting effects it is first necessary to compute the contribution of the simple sequential model (SSM) process in which a π^+ first changes a neutron into a proton becoming a π^0, and then the π^0 changes another neutron into a proton [see Fig. 1(d)]. In this process the intermediate state is a π^0 plus the analog of the target ground state. Any significant difference between the predictions of the SSM and the experimental data is taken as evidence for the importance of interesting two-nucleon effects.

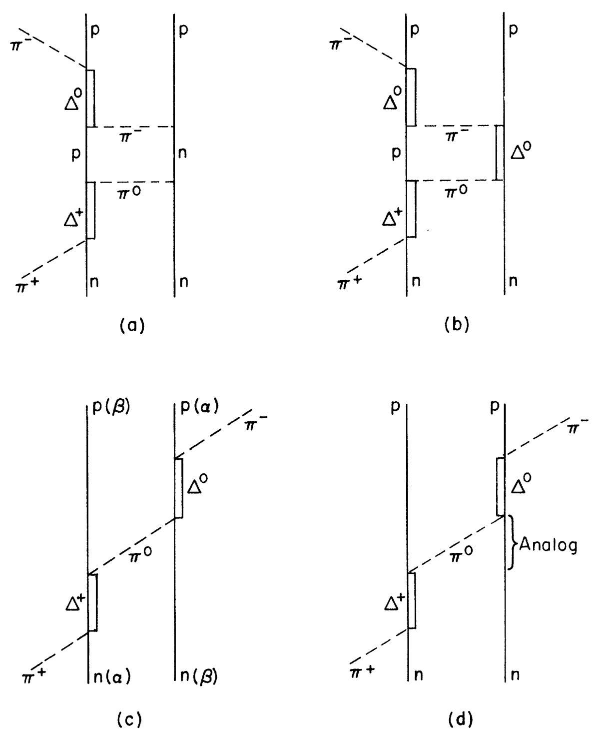

FIG. 1. Reaction mechanisms. Dashed lines are pions and solid lines are nucleons. For simplicity in presentation, all pion-nucleon scatterings are taken to proceed through the delta or nucleon pole terms.

In this note comparisons between predictions of the SSM and the data of Refs. 1–3 are made. The details of these coupled-channel calculations are described in Ref. 4. Here we use the version which employs the Kisslinger potential (no angle transformation), and the Woods-Saxon density ($r_n = r_p = 1.1$ fm; $a_n = a_p = 0.54$ fm).

Our first comparison between theory and experiment is shown in Fig. 2, in which the 5° cross sections are plotted as a function of energy. The targets are ^{18}O,[2] ^{26}Mg,[2] and ^{42}Ca.[3] In each case the SSM compares quite well with that data at energies greater than about 200 MeV. At lower energies there is significant disagreement. A qualitative explanation for the observed energy dependence shown has been obtained from the black disk model by Johnson.[6] (His calculations also employ the SSM, and the similar nature of our results demonstrates the validity of the semiclassical approximations that he uses.)

Recently, the double analog of ^{209}Bi has been observed[4] at 292 MeV. A comparison between the SSM and the 5° data on ^{18}O, ^{26}Mg, ^{42}Ca, and ^{209}Bi is made in Fig. 3. Very good agreement over a broad range of targets is achieved at 292 MeV.

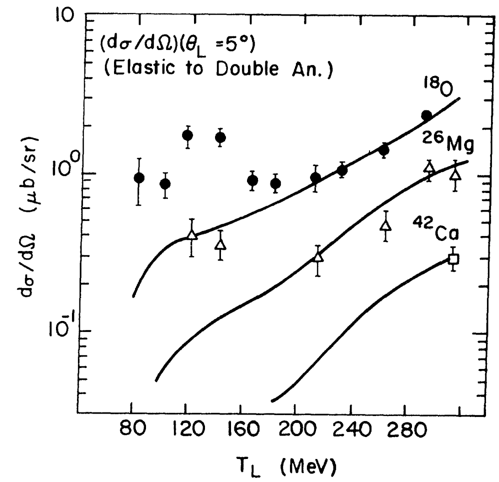

FIG. 2. Forward angular distributions. The ^{18}O and ^{26}Mg data are from Ref. 2 and the ^{42}Ca datum is from Ref. 3.

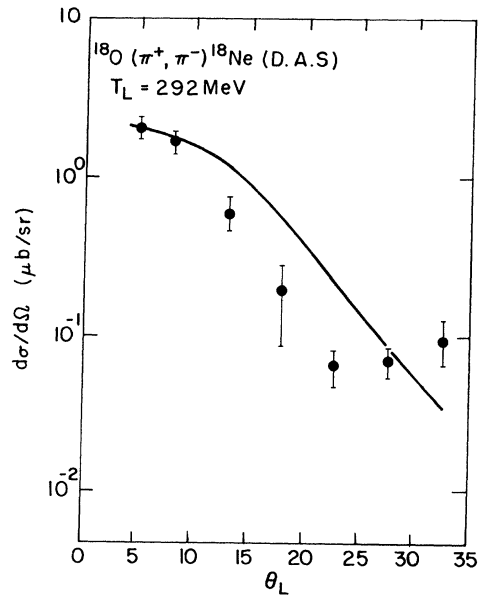

FIG. 4. Angular distribution for $^{18}O(\pi^+, \pi^-)^{18}Ne$ (double analog state) at 292 MeV.

Next we consider angular distributions. The one for the ^{18}O target at a pion energy of 292 MeV is shown along with the SSM prediction in Fig. 4. At this relatively high energy there is qualitative agreement between theory and experiment.

Completely different is the situation at 164 MeV, as displayed in Fig. 5. Here the SSM fails badly, missing both the magnitude of $(d\sigma/d\Omega)$ (5°) and, more importantly, the position of the first minima. The large deviation (~20°) between the predicted and observed positions of this minima is an extraordinary occurrence and is certainly the signature of the importance of interesting two-nucleon effects.[1]

The conclusions of this study are as follows: At relatively high energies (greater than about 250 MeV) the SSM works quite well and may be used with reasonable confidence in spectroscopic studies. At energies in the vicinity of the pion-nucleon (3, 3) resonance the SSM fails, and this lack of success provides us with strong evidence that interesting two nucleon processes occur.

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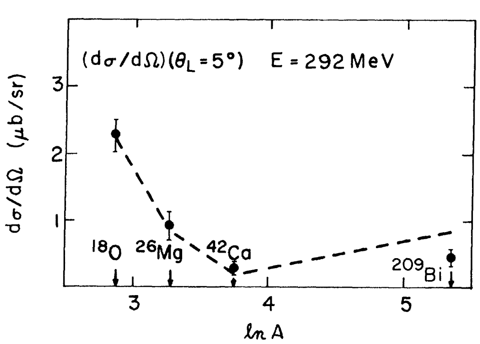

FIG. 3. Target dependence of $(d\sigma/d\Omega)$ $(\theta_L = 5°)$.

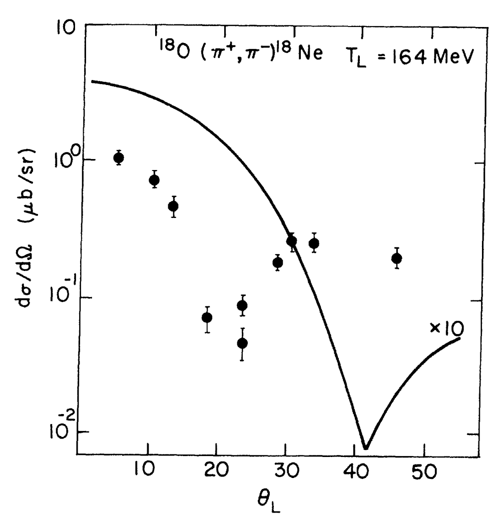

FIG. 5. Angular distribution for $^{18}O(\pi^+, \pi^-)^{18}Ne$ (double analog state) at 164 MeV.

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