PHYSICAL REVIEW C VOLUME 18, NUMBER 4 OCTOBER 1978

Pion-induced double charge exchange on ^{18}O

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(Received 17 February 1978)

The reaction $^{18}O(\pi^+,\pi^-)$ ^{18}Ne(g.s.) is calculated using the optical model, including coupling through the 0^+, 2^+, and 4^+ states in ^{18}F. In addition to the analog, the 2^+ and 4^+ intermediate states are found to be quite important between 100 and 200 MeV. Good agreement is obtained with the experimental cross sections at 0°.

[NUCLEAR REACTIONS $^{18}O(\pi^+,\pi^0)$ ^{18}F(lowest $T=1$ levels), $T_\pi=139$, $^{18}O(\pi^+,\pi^-)$ ^{18}Ne (g.s.) $T_\pi=100$, 139, 187. Calculated $\sigma(\theta)$.]

The pion double charge exchange reaction has excited theoretical and experimental interest for some time due to its unique position as a $\Delta T=2$ reaction induced by a fundamental particle. The recent data coming from LAMPF[1-3] and SIN,[4] has rekindled this interest. Published 0° or 18° cross sections exist now for ^{18}O at several energies, and for ^{16}O at 139 MeV. Preliminary results are also available for several other nuclei.

The double charge exchange reaction $^{18}O(\pi^+,\pi^-)$ ^{18}Ne(g.s.), proceeding to the double analog of the target state, is studied here in the framework of optical model calculations, which allow explicit inclusion of several intermediate states of the ^{18}F nucleus. The cross section for this reaction proceeding through the first excited 2^+ state is found to be comparable to that of the 0^+ analog state. A simple estimate of the contribution of the 4^+ state indicates that although substantially smaller it has a significant effect on the 0° cross section since the different intermediate states all contribute coherently. Good agreement is obtained with the existing data at 0° only if the double quadrupole process through the 2^+ state is included. Finally, the wide variance of theoretical predictions[5-7] pointed out in Ref. 1 is explained by the large nonanalog contributions.

The calculations presented here employ a coupled channels optical potential using a Kisslinger or $\vec{k}\cdot\vec{k}'$, prescription for the p-wave part of the pion-nucleon amplitude, which was then transformed to the pion nucleus system. Calculations using a local or $(1-q^2/2k^2)$ prescription were also performed. These led to results very similar to those obtained with the Kisslinger potential, although the double charge exchange cross sections were generally slightly smaller.

The diagonal potential for scattering from the nucleus in state $|i\rangle$ in Kisslinger form is then, in the notation of Ref. 8:

$$U_{ii}(r) = -b_0^{(ii)}k^2\rho(r) + \vec{\nabla}\cdot b_1^{(ii)}\rho(r)\vec{\nabla}. \quad (1)$$

Here $b_0^{(ii)}$ and $b_1^{(ii)}$ are combinations of the various s- and p-wave pion-nucleon phase shifts, which depend upon the details of state $|i\rangle$. Coupling potentials are given by

$$U_{fi}(\vec{r}) = b_0^{(fi)}k^2\rho_{fi}(\vec{r}) + \vec{\nabla}\cdot b_1^{(fi)}\rho_{fi}(\vec{r})\vec{\nabla}. \quad (2)$$

In this expression $\rho_{fi}(\vec{r})$ is the transition density,

$$\rho_{fi}(\vec{r}) = \sum_{\alpha=1}^{A}\langle\psi_f(\vec{r}_\alpha)|\,\delta(\vec{r}-\vec{r}_\alpha)\,|\psi_i(\vec{r}_\alpha)\rangle\,, \quad (3)$$

and is a function of the vector $\vec{r}$ for nonzero l transfers. The pion-nucleon phase shifts have been taken from the recent parametrization of Rowe, Salomon, and Landau.[9]

The wave functions of the lowest three $T=1$ of the mass-18 system were taken to be pure $(d_{5/2})^2$ configurations in a harmonic oscillator shell model. The oscillator length parameter used was $b=1.769$ fm. This model underestimates the measured $B(E2)$[12] from the 2^+ to the ground state in ^{18}Ne. To obtain the correct $(E2)$ strength, the transition density has been renormalized without abandoning the $(d_{5/2})^2$ form. This may appear to be a cavalier treatment of the structure; however, adjustment to the observed $B(E2)$ guarantees the right amount of collectivity, even though the radial dependence may be incorrect. This procedure cannot be used for the 4^+ state, since there is no measured $B(E4)$ in ^{18}NE. Since only the $(d_{5/2})$ orbital can contribute to an $E4$ process, these cal-

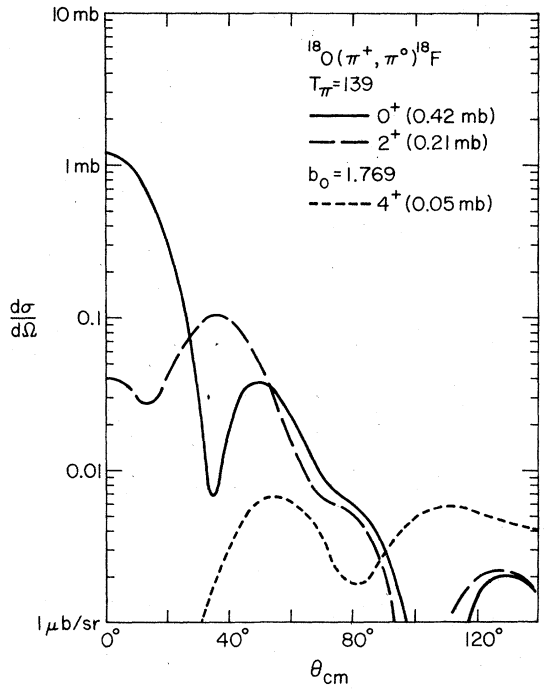

FIG. 1. Single charge exchange cross sections $^{18}O(\pi^+, \pi^0)^{18}F$, 0^+, 2^+, 4^+, $T=1$. The numbers in parentheses are the integrated angular distributions.

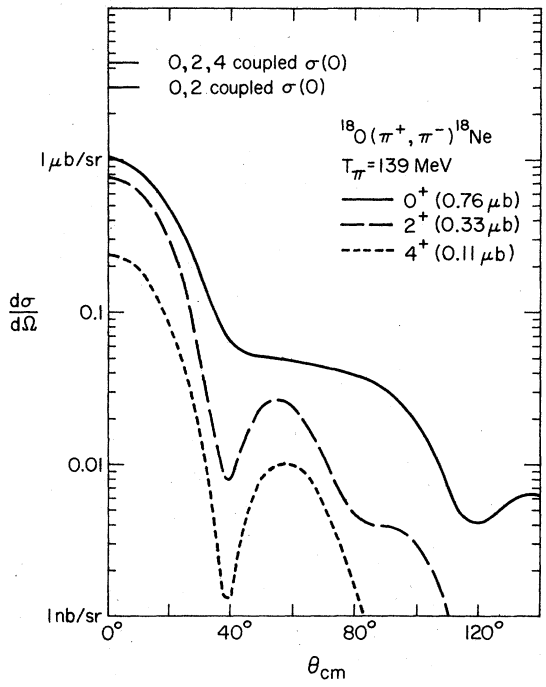

FIG. 2. Calculated $^{18}O(\pi^+, \pi^-)^{18}Ne$(g.s.) cross sections assuming a single ^{18}F state (either 0^+, 2^+, or 4^+) contributes. Also shown are the 0° cross sections for the 0^+ and 2^+, and 0^+, 2^+, and 4^+ intermediate states coupled together.

culations probably overestimate the contribution of the 4^+.

Very recently, it has been shown[10,11] that careful treatment of the nuclear structure is important to an understanding of the $^{18}O(\pi^+, \pi^-)^{18}Ne$ reaction. These calculations have used closure either to estimate or calculate the effects of configuration mixing. The main effect of the configuration mixing in these calculations is to enhance the various quadrupole transition matrix elements. In this work, the coherence of the quadrupole transitions is built in by adjusting the normalization of the transition density to the observed $B(E2)$.

In order to illustrate the importance of the intermediate states in ^{18}F, the single charge exchange cross sections to the $T=1$, 0^+, 2^+, and 4^+ states are shown in Fig. 1. These cross sections have characteristic $L=0$, 2, and 4 angular distributions, and the integrated cross sections are in the ratio of approximately 8:4:1. Naively one might expect the 0° double charge exchange cross section through a specific intermediate state to scale as the integrated single charge exchange cross section squared, i.e., 64:16:1. In Fig. 2 the angular distributions are presented, and the 0° cross sections are seen to be in ratio closer to 4:3:1. All three curves, of course, show a characteristic $L=0$ angular distribution. These contributions will interfere coherently, leading to the indicated 0° cross sections due to the 0^+ and 2^+ together, and the 0^+, 2^+, and 4^+ together. The effect of 0° of including the 2^+ is an increase of a factor of 3 over the double analog channel alone. This ratio at 0° holds approximately constant, from 100 to 187 MeV, for varied oscillator length parameters, and for local potentials as well as the Kisslinger form.

In addition to configuration mixing, the radial dependence of the single particle wave functions is an aspect of nuclear structure to which the reaction may be sensitive. This was studied by increasing the oscillator length parameter for the valence nucleons to $b=1.95$, while leaving the core unchanged. The normalization of ρ_{fi} was changed for the $(E2)$ transition so that the $B(E2)$ was held constant. The effects on single charge exchange are negligible, and for the double charge exchange there is approximately a 30% reduction in the cross sections with essentially no change in shape. This holds for the calculated cross section due to each intermediate state separately, as well as for the coherent sum.

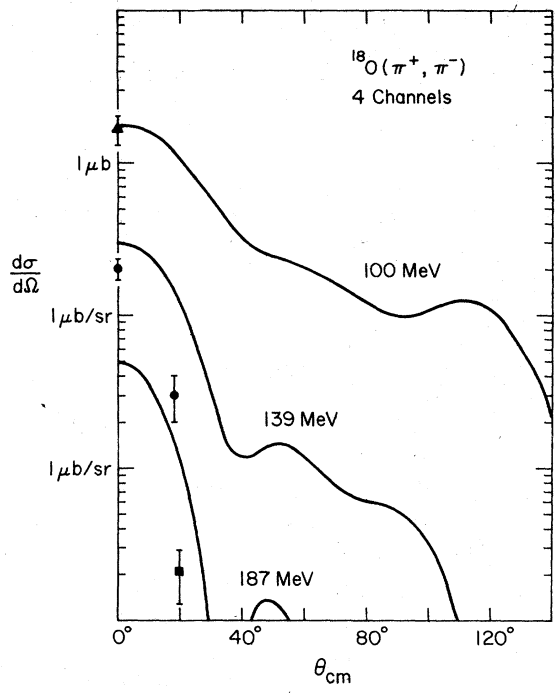

FIG. 3. Comparison of $^{18}O(\pi^+, \pi^-)^{18}Ne$(g.s.) calculations with existing data. The symbol ⊥ represents 95 MeV data, ⊥ represents 139 MeV, and ⊥ represents 187 MeV.

Presented in Fig. 3 are calculations of the double charge exchange reaction at 100, 139, and 187 MeV, including only the 0^+ and 2^+ intermediate states. The energies were chosen to compare with the existing data at 0° and 18°. Given the simplifications in the calculations the agreement at 0° is reasonable. The slopes of the theoretical cross sections, however, are much smaller than the experimental slopes. Modest variations in the nuclear size have no effect on the calculated slope.

These calculations also exhibit the source of the wide variation between the local potential calculations of Ref. 5, which included only the 0^+ intermediate states, and the fixed scatterer calculations of Ref. 6 using a nonlocal two-body interaction. Both these calculations were done in a $(d_{5/2})^2$ model, and the results differed by a factor of 10 at 0°. We obtain a factor of 2 increase in going from a local to a nonlocal potential, and a further factor of 4.5 as the 2^+ and 4^+ intermediate states are added. The discrepancy in the integrated cross section is similarly resolved. A third point which should be stressed is that attempts to deduce how important a particular intermediate state may be by looking at the single charge exchange can be very misleading, as can be seen from Figs. 1 and 2.

Calculations are now in progress on ^{16}O and ^{18}O using more detailed wave functions. A careful study, in this context, of the difference between use of closure on a detailed ground state wave function and explicit iteration of intermediate states using coupling strengths determined from other reactions is certainly needed.

To summarize, these results show the importance of nonanalog contributions to double charge exchange scattering to a double analog state. Recognizing this importance enables one to understand the large difference among earlier calculations, and to obtain quantitative agreement with the measured cross section at 0°. Finally, the slope of the measured cross sections from 0° to 18° is not well described by the calculations, although inclusion of the nonanalog processes helps.

The authors would like to thank E. Rost for several useful conservations. One of us. (D.A.S.) also acknowledges interesting discussions with S. J. Wallace and W. J. Gerace. Support from the University of Maryland Computer Sciences Center was used for many of the calculations presented here. This work was supported in part by U. S. Department of Energy.

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