Search for an η bound state in pion double charge exchange on ^{18}O

J. D. Johnson,(1) G. R. Burleson,(4) C. Edwards,(5) M. El-Ghossain,(4)
M. A. Espy,(5) R. Garnett,(3) A. Hussein,(2) K. Johnson,(1) C. F. Moore,(1)
C. L. Morris,(3) J. M. O'Donnell,(3) M. Palarczyk,(5) M. Rawool-Sullivan,(3,4)
H. Ward,(1) D. Watson,(7) C. Whitley,(1) and A. L. Williams(6)
(1) *The University of Texas at Austin, Austin, Texas 78712*
(2) *King Fahd University of Petroleum and Minerals, Dhahran 31261 Saudi Arabia*
(3) *Los Alamos National Laboratory, Los Alamos, New Mexico 87545*
(4) *New Mexico State University, Las Cruces, New Mexico 88003*
(5) *University of Minnesota, Minneapolis, Minnesota 55455*
(6) *University of Pennsylvania, Philadelphia, Pennsylvania 19104*
(7) *University of York, York Y01-5DD, United Kingdom*
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The search for an η bound state in the double charge exchange (DCX) reaction to the double isobaric analog state (DIAS) ^{18}O(π^+,π^-)^{18}Ne(DIAS) has been carried out at LAMPF using the P^3 channel and the LAS spectrometer. An excitation function for this reaction was measured for energies ranging from 350 to 440 MeV and for momentum transfers of 0, 105, and 210 MeV/c. The measured cross sections tend to agree with previous results for DCX on ^{18}O. The measured excitation function shows some evidence for structure near the η production threshold.

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Coupled-channel calculations by Bhalerao and Liu have shown that the η-N interaction is attractive for nuclei with $A \geq 12$ [1]. Recent calculations by Haider and Liu [2] have predicted that a bound state between an η and a nucleus may occur as an intermediate state in pion double charge exchange (DCX). Such an effect would compete with π° and η channels in the continuum. The existence of such a mesic nucleus would lead to a resonancelike structure in the DCX excitation function at fixed momentum transfer, due to the interference between these channels. Calculations made for the reaction ^{14}C(π^+,π^-)^{14}O(DIAS) predict that this structure should occur with a fluctuation ratio of $(\sigma_{\max}-\sigma_{\min})/\sigma_{\text{average}} \sim$ 79% for DCX reactions at a momentum transfer of q = 210 MeV/c [2]. It should occur at the η production threshold with a width on the order of 10 MeV and add to the smoothly varying continuum amplitude. It should be noted that because of the greater level density compared to ^{14}C, the fluctuation ratio for ^{18}O may be smaller. Chiang *et al.* predict that the width of the η bound state for a nucleus like oxygen will be around 30 MeV or larger [3]. If the width is larger than the 10 MeV predicted for ^{14}C then the fluctuation ratio will also be smaller. Haider and Liu [2] note that if the width is a factor of four greater than the 10 MeV expected, the fluctuation ratio should still be $\sim$ 20% at $q = 210$ MeV/c. For the reaction ^{18}O(π^+,π^-) (DIAS) the η threshold occurs when the η is bound in the first nuclear orbital of ^{18}F [2]. Taking into account the excitation energy to the isobaric analog state ($T = 1$) in ^{18}F, the resonance effect should be seen at 420 MeV.

Lieb *et al.* [4] have seen possible evidence of an η bound state from studies of the reaction $A(\pi^+,p)\eta A$-1. However, Chrien *et al.* [5], found no evidence of the creation of an η bound state with width $\sim$ 9 MeV, but their upper limit, for a fluctuation ratio $\frac{1}{3}$ of the predicted size, is larger than that estimated by Haider and Liu. This paper reports an attempt to confirm this new type of nuclear matter with an experiment at LAMPF devised to search for an η-nucleus bound state in the DCX reaction ^{18}O(π^+,π^-) (DIAS). The excitation function for this reaction was measured for momentum transfers of q = 0, 105, and 210 MeV/c for energies ranging from T_π = 350 to 440 MeV.

This experiment was carried out using the Large Acceptance Spectrometer (LAS) in the P^3 East channel at LAMPF, as configured for DCX measurements [6,7]. The P^3 channel was tuned for a dispersed beam with a horizontal dispersion of 2 cm/%, giving a beam spot of about 2.5 cm (horizontal) $\times$ 3.5 cm (vertical) and an energy resolution of 0.15%, delivering approximately $1-2\times10^7$ pions/s to the LAS spectrometer.

The LAS spectrometer consists of a C magnet, a quadrupole doublet, a 45° dipole magnet, two pairs of drift chambers, a Cherenkov detector, and two scintillators. To minimize multiple scattering, helium bags were installed after the target chamber and through to the rear chamber. The C magnet was used to sweep away protons and positive pions and gave a 10° horizontal bend to particles with momentum matched to the spectrometer. The LAS spectrometer has a momentum acceptance of $\pm$ 8% in dp/p, a horizontal angular acceptance of $\pm$3.5°, a vertical angular acceptance of $\pm$2.5°, and it subtends a maximum solid angle of $\Delta\Omega \sim$12 msr. There was one pair of delay-line readout drift chambers located before and one pair after the dipole, which were used for particle tracking. The gas threshold Cherenkov detector contained isobutane and was used to eliminate electron events. Two scintillators were used to determine time of flight for particle identification. The hardware trigger required that both scintillators fire in coincidence with either of the front chambers. The incident pion flux was monitored by a thin ion chamber immediately upstream of the target chamber. Measurements were carried out both in 1991 and 1992.

The target was liquid H_2O with an isotopic purity for ^{18}O of 94%. The active area of the target measured 6.66 cm (horizontal) $\times$ 7.56 cm (vertical), and the target windows were made of 0.1588 cm CH_2. By using both CH_2 and ^{18}O targets with hydrogen kinematics, it was possible to cross-normalize and experimentally determine the ^{18}O target areal density. After taking into account the isotopic purity, the ^{18}O areal density was 1.72 g/cm^2. The CH_2 areal density was measured to be 0.294 and 0.288 g/cm^2 for the 1991 and 1992 runs, respectively.

DCX runs for the reaction $^{18}O(\pi^+,\pi^-)^{18}Ne$ (DIAS) were taken at 5° ($q \approx 0$) and for fixed momentum transfers of $q = 105$ and 210 MeV/c. Normalization measurements were made for DCX runs at each energy using the CH_2 target with hydrogen kinematics at 40°. Normalization runs at a particular energy were taken before or after the DCX runs at that energy. The only difference between DCX runs at a particular energy was the spectrometer and target angles and beamline jaw settings. This should be a consistent and robust method of determining yields and cross sections.

The cross section for the low-lying 2^+ state in ^{18}Ne increases significantly with angle relative to the ground state, and there is also a possible contribution from a $(0^+, 2^+, 4^+)$ triplet near 3.6 MeV. With an experimental resolution of 2.3 MeV [full width at half-maximum (FWHM)], it is not possible to resolve the ground state (DIAS) from the low-lying states, therefore no attempt to separate these states was made. The results reported here for $q = 0$, were obtained by summing counts inside of 7 MeV placed around the 0^+ and 2^+ states in the missing-mass histogram. For higher momentum transfers, the number of counts in the 0^+ and 2^+ states drops off significantly, therefore the number of counts in these states was determined by setting a 7-MeV gate in the same position as for the $q = 0$ case. Figure 1 shows missing-mass histograms for ^{18}O for $q = 0$, 105, 210 MeV/c, with a 7-MeV gate set as described above. Elastic scattering of π^+ on ^1H was measured at each energy and absolute normalizations were obtained from the phase-shift program of Arndt, SAID [8].

The measured cross sections were found to agree with previously published data in this energy range [7, 9], which also did not separate the ground state from adjacent states. The cross sections determined in this experiment are listed in Table I and plotted in Fig. 2 along with previously published results for the $^{18}O(\pi^+,\pi^-)^{18}Ne$(DIAS) reaction.

Systematic normalization errors can be reduced by taking a ratio of the $q = 210$ to $q = 0$ MeV/c cross sections. Beam normalization errors will cancel in this ratio. A check of this assumption is provided by the data in the

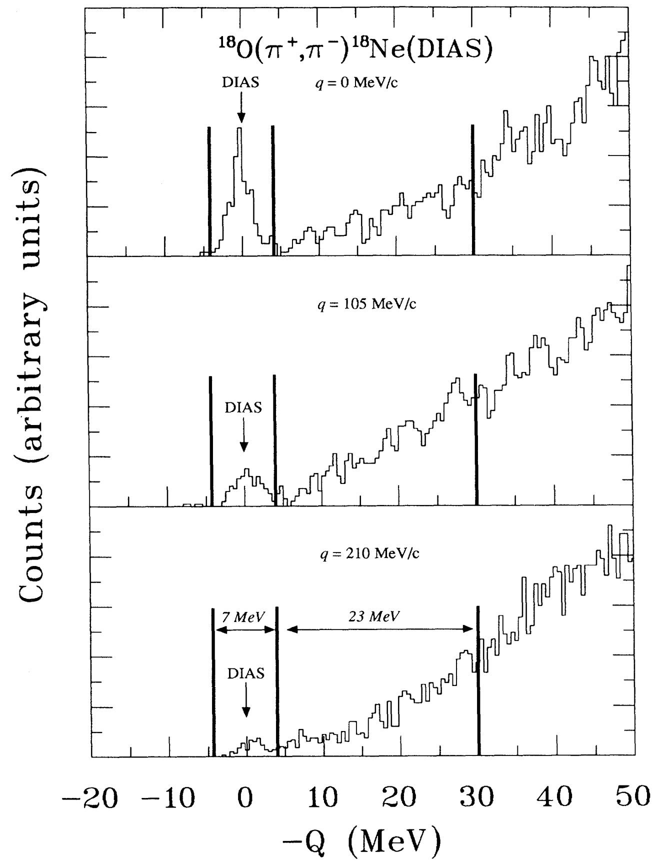

FIG. 1. Missing-mass spectra in arbitrary units for the reaction $^{18}O(\pi^+,\pi^-)^{18}Ne$(DIAS) at 420 MeV. A 7-MeV gate was set around the centroid of the $q = 0$ MeV/c DIAS peak and the same gate was used for the other momentum transfers.

unbound region of ^{18}Ne. For these states there should be no structure, as the mechanism involved is clearly a two-step process. The solid circles in Fig. 3 show this ratio for a missing energy bite of 23 MeV above the ground state. A fit to the data with a straight line gives $\chi^2/N_{DF} = 1.45$. Within errors this ratio is a constant function of beam energy. The ratio for the bound-state region is shown

TABLE I. The center-of-mass differential cross sections ($\mu b/sr$) for $^{18}O(\pi^+,\pi^-)^{18}Ne$(DIAS) using a 7-MeV gate.

T_π	$d\sigma/d\Omega$		
(MeV)	q=0	q=105	q=210 MeV/c
350	3.76 ± 0.30		0.47 ± 0.04
390	2.27 ± 0.20		0.44 ± 0.04
400	2.32 ± 0.16		0.41 ± 0.05
410	2.19 ± 0.17	1.28 ± 0.13	0.40 ± 0.03
415	2.21 ± 0.36		0.37 ± 0.06
420	2.63 ± 0.20	1.01 ± 0.14	0.38 ± 0.03
430	2.81 ± 0.31	1.15 ± 0.13	0.50 ± 0.06
440	1.97 ± 0.32		0.38 ± 0.06

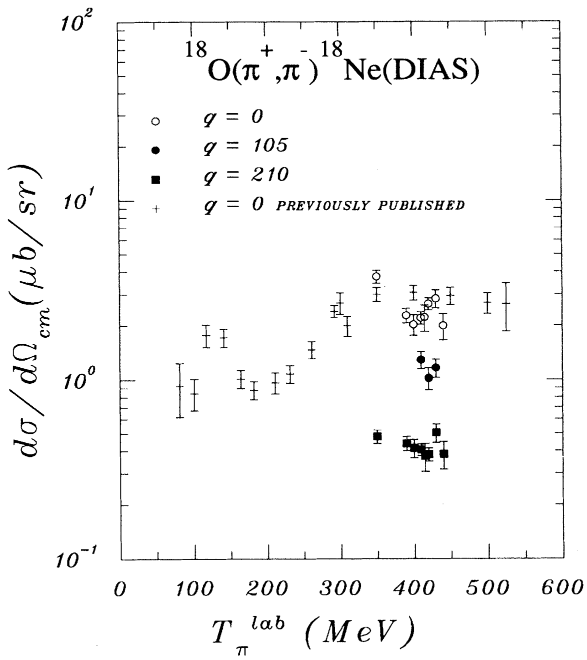

FIG. 2. Differential cross sections from this experiment and previously published data for the reaction $^{18}O(\pi^+,\pi^-)^{18}Ne(DIAS)$.

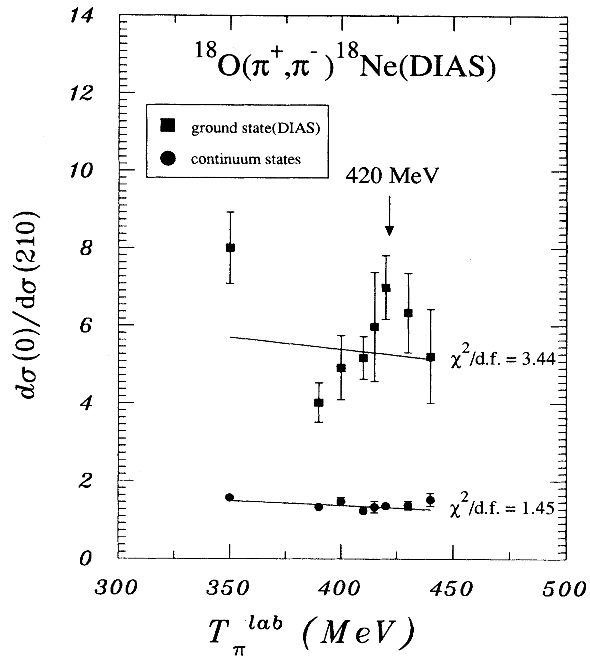

FIG. 3. Ratios of the $q = 0$ and $q = 210$ MeV/c cross sections plotted with best straight line fits for DIAS and continuum states.

by solid squares in Fig. 3. The fit to the data with a straight line gives $\chi^2/N_{\rm DF} = 3.44$, indicating there may be structure in the eta threshold region. Unfortunately the statistical precision of the data is not sufficient to allow more than a qualitative characterization of this effect. The maximum fluctuation ratio in the data is $\sim 60\%$ for a peak centered near 420 MeV and with a width on the order of 25 MeV.

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