BRIEF REPORTS

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Angular distributions for the double isobaric analog and a $T_<$ state at high excitation in pion double charge exchange on ^{93}Nb

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The double isobaric analog state |IAS⊗IAS⟩ and a new resonance below the |IAS⊗IAS⟩ have been observed in pion-induced double-charge-exchange reactions on ^{93}Nb. Angular distributions have been measured for both transitions. The cross section observed for the $T_<$ resonance is 21% of that for the |IAS⊗IAS⟩ in ^{93}Tc. We mention various possibilities for the nature of the observed resonance but have no unique explanation for its large cross section.

We report the observation of the double isobaric analog |IAS⊗IAS⟩ in the $^{93}\mathrm{Nb}(\pi^+, \pi^-)^{93}\mathrm{Tc}$ reaction. In addition we have measured a new resonance at high excitation energy below the |IAS⊗IAS⟩. The observation of this resonance with such a large cross section is unexpected. We will describe its properties as observed in the double-charge-exchange (DCX) reaction and suggest possible identifications.

The measurements were performed with the energetic pion channel and spectrometer (EPICS) at LAMPF with the standard pion-DCX setup [1]. The target was natural niobium (100% ^{93}Nb). Measurements were taken at T_π = 295 MeV and at scattering angles of 5°, 10°, 15°, 20°, and 30°. Electrons were eliminated using a isobutane-gas velocity-threshold Cherenkov detector in the focal plane. A scintillator placed behind a series of graphite blocks was used to detect and veto muon events [2]. The remaining background is pions resulting from continuum DCX on the target. The choice of the highest beam energy available at EPICS (T_π = 295 MeV) for the present measurements had the advantage of producing the largest cross sections measurable for the |IAS⊗IAS⟩.

The acceptance of the spectrometer was measured by pion scattering from ^{12}C at a given angle, varying the spectrometer field to cover an outgoing pion momentum range of about ±10% of the central momentum of the spectrometer. Absolute normalizations were obtained by measuring π–p scattering from a polyethylene (CH_2) target of areal density 25.7 mg/cm^2 and comparing the yields with cross sections calculated using π-nucleon phase shifts [3].

Figure 1 shows the ^{93}Nb Q-value spectrum at a scattering angle of 5°. The spectrum has been corrected for the spectrometer acceptance as a function of momentum. The background (dashed line), which arises from DCX to discrete low-lying states and to the continuum, was fitted

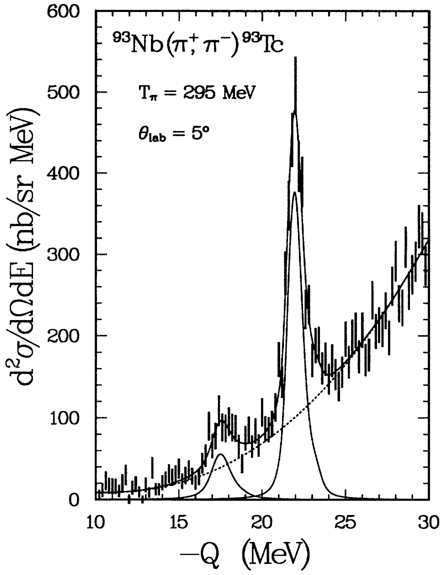

FIG. 1. Double differential cross-section spectrum for the (π^+, π^-) reaction on a ^{93}Nb target at $T_\pi = 295$ MeV and $\theta_{\rm lab} = 5°$. The larger peak to the right at $Q = -21.9$ MeV is the double isobaric analog state $|{\rm IAS} \otimes {\rm IAS}\rangle$ and the smaller peak to the left at $Q = -17.4$ MeV is the new resonance discussed herein. Another weaker state is probably present at $Q = -14.4$ MeV.

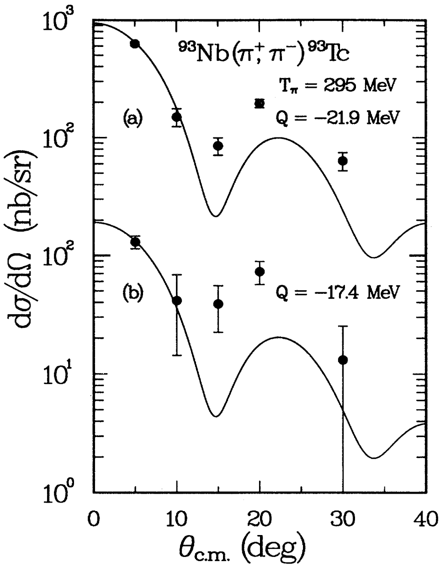

FIG. 2. (a) Angular distribution for the $|{\rm IAS} \otimes {\rm IAS}\rangle$ peak, at $Q = -21.9$ MeV in the double-charge-exchange spectrum on ^{93}Nb shown in Fig. 1. The cross sections have been extracted with use of a Lorentzian shape convoluted with the elastic line shape with constant width of 0.9 MeV and constant $Q = -21.9$ MeV. The solid line shows a sequential model calculation for the $|{\rm IAS} \otimes {\rm IAS}\rangle$ through the isobaric analog state as an intermediate state, normalized arbitrarily to the data. (b) Same as above but for the strongest $T_<$ peak, at $Q = -17.4$ MeV with $\Gamma = 1.4$ MeV. The solid line is the calculation for the $|{\rm IAS} \otimes {\rm IAS}\rangle$ normalized to the forward-angle datum.

using a third-order polynomial in Q value. It was found that comparable fits and cross sections are obtained if, instead, fourth- or higher-order polynomial shapes are used for the background. The solid line is the resulting fit to the spectrum with the widths and centroid energies free parameters. The spectrum shown in Fig. 1 and the spectra measured at other angles were obtained in long DCX runs with about 100 hours of beam time per angle to accumulate good statistics. For example, the $|{\rm IAS} \otimes {\rm IAS}\rangle$ peak in the spectrum at 5° shown in the figure has about 850 counts in the peak above the background level. The width of the $|{\rm IAS} \otimes {\rm IAS}\rangle$ peak in Fig. 1 is due primarily to the experimental resolution (which is dominated by straggling in the target). In addition to the $|{\rm IAS} \otimes {\rm IAS}\rangle$ at $E_x = 19.3$ MeV ($Q = -21.9$ MeV), the spectra show the existence of a wider peak located 4.5 MeV below the $|{\rm IAS} \otimes {\rm IAS}\rangle$. It is most clearly observed in the 5° spectrum. At 10° both resonances are very weak and almost vanish, but they show up again clearly at 20°. The cross section at 5° is 630 ± 30 nb/sr for the $|{\rm IAS} \otimes {\rm IAS}\rangle$ and 130 ± 20 nb/sr for the new resonance (at 4.5 MeV below the $|{\rm IAS} \otimes {\rm IAS}\rangle$). There is another possible weaker state 7.5 MeV below the $|{\rm IAS} \otimes {\rm IAS}\rangle$ ($Q = -14.4$ MeV) with a 5° cross section of only 26 ± 10 nb/sr. Both states are at the edge of the spectrometer acceptance, appearing at $\delta = 6.0\%$ and 7.2%, respectively.

In addition to the data at 5°, we have measured angular distributions for both the $|{\rm IAS} \otimes {\rm IAS}\rangle$ and this 14.8-MeV state. This is the first angular distribution reported for the $|{\rm IAS} \otimes {\rm IAS}\rangle$ in a heavy nucleus and is presented in Fig. 2. We find that the angular distributions for the 14.8-MeV state and the $|{\rm IAS} \otimes {\rm IAS}\rangle$ on ^{93}Nb are the same within statistical errors. The 11.8-MeV state is too weak at larger angles to allow extraction of an angular distribution. The curves are simple sequential-model calculations $(\pi^+, \pi^0)(\pi^0, \pi^-)$, assuming only the $|{\rm IAS}\rangle$ as an intermediate state and have been normalized to fit the data. It is not clear whether additional peaks are a general feature of forward-angle DCX spectra at 300 MeV in heavy nuclei. Such a peak is present in previous data [4] for the reaction ^{56}Fe$(\pi^+, \pi^-)^{56}$Ni. Tables I and II summarize the present results.

In heavy nuclei the description of the $|{\rm IAS}\rangle$, with $T_>$ isospin, implies that another state of the same space-spin configuration and orthogonal wave function with $T_<$ isobaric spin may exist. In the general case, with n_s shells

TABLE I. Results from (π^+, π^-) double charge exchange at an incident pion energy $T_\pi = 295$ MeV and $\theta_{\rm lab} = 5°$.

Q (MeV)	$d\sigma/d\Omega^{\rm max}_{\rm exp}$ (nb/sr)
−14.4	26 ± 10
−17.4	130 ± 20
−21.9	630 ± 30

TABLE II. Cross sections as a function of scattering angle for the |IAS⊗IAS⟩ and the strongest $T_<$ state observed in ^{93}Nb(π^+, π^-)^{93}Tc at $T_\pi = 295$ MeV.

	$d\sigma/d\Omega$	
θ_{lab} (deg)	$Q = -17.4$ MeV (nb/sr)	$Q = -21.9$ MeV (nb/sr)
5	130 ± 16	630 ± 22
10	41 ± 27	150 ± 26
15	39 ± 16	85 ± 14
20	73 ± 16	195 ± 16
30	13 ± 12	63 ± 11

occupied by the excess neutrons, there are $(n_s - 1)$ components of the $T_<$ states all having the same shell structure and total isospin but different intermediate isospin quantum numbers. The choice of coupling schemes is not unique and one can speak only of a set of $T_<$ states. In the nucleus these configurations are mixed via residual interactions both with each other and with the surrounding sea of more complicated $T_<$ shell-model states. Theoretical investigations [5–13] have been made for various features of these states, such as spreading, splitting, energy, and width. Several single-particle transfer reactions have measured [14–18] their properties.

A comparison of angular distributions measured for pion-induced cross sections for $\Delta J = 0$ transitions reveals that the minima occur at smaller angles for states that are orthogonal in space to the initial state than for states which are not [19,20]. This may be a consequence of an additional radial node in the form factor for states that are orthogonal in space to the initial state, or the minima locations may be merely indicative of the effective radius of the appropriate transition density. In the present case, if we use a squared Bessel function, $J_0^2(qR)$, to estimate the location of the minima in Fig. 2, we obtain $13.8° \pm 0.6°$ for the |IAS⊗IAS⟩ and $12.0° \pm 1.0°$ for the $T_<$ state.

How does one excite this $T_<$ state in ^{93}Tc? One possibility is Coulomb mixing with the |IAS⊗IAS⟩. But, for this mechanism to explain the current data, the charge-dependent matrix element needs to be several times larger than that obtained from simple estimates. A matrix element of 800–900 keV, which would be needed to explain the measured ratio, is unusually large. Alternative mechanisms are possible. The pion-DCX transition operator contains, of course, components which are not necessarily proportional to the total isospin operator $\boldsymbol{T}_N$. Such components may induce transitions to states in the final nucleus other than the |IAS⊗IAS⟩, and the final isospin may be different from the initial isospin T. It is enticing to conjecture that this resonance might be connected with a double Gamow-Teller transition. The double Gamow-Teller transition involves double spin-flip as the mechanism for exciting the state, but recent calculations [21] suggest that double spin-flip is strong at lower energies and should be negligible at $T_\pi = 295$ MeV. Another possibility is the correlations in shell-model wave functions that allow transitions to proceed through intermediate states other than the analog state [22]. At 300 MeV, these are known to significantly affect the A dependence of the cross sections for DCX on $f_{7/2}$ shell nuclei [22, 23], and they could lead to the excitation of other $\Delta J = 0$ states. However, this mechanism is expected to excite several of the $\Delta J = 0$ states in the final nucleus that can be reached via recoupling the two participant neutrons to $\Delta J = 0$ and should not selectively excite only one.

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