^{88}Sr($\vec{p}$,π$^-$) REACTION TO HIGH SPIN, 2p-1h STATES IN ^{89}Zr

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An striking feature of proton induced negative pion production (p,π$^-$) on nuclei, is the selective excitation of two-particle (protons), one-hole (neutron), high-spin stretched (and nearly stretched) states at low excitation energy in the residual nuclei.[1] These states have been found to be most strongly excited in target nuclei where the high spin j$_>$ neutron orbital is full and the corresponding proton orbital empty. This and a number of the other observed systematics of these highly selective excitations can be understood qualitatively[1] in terms of a two-nucleon reaction mechanism for A(p,π$^-$)A+1; i.e., the underlying NN process for π$^-$ production in the nucleus is p + n → p + p + π$^-$. In this view, the incoming proton interacts with a target neutron (in a high spin orbital), producing a neutron hole and two residual protons which couple to maximum or nearly maximum spin in order to accommodate the high linear momentum transfer inherent to pion production reactions. Implicit in this discription is the lack of direct participation of the core nucleons in the production process, an ansatz supported by our earlier studies of (p,π$^-$) ground state transitions from the carbon isotopes.[2]

Using the high intensity polarized proton beams available at IUCF, target nuclei where the excitation of the stretched 2p-1h states are most pronounced have recently been studied. Both cross section and analyzing power distributions have been measured for the stretched and nearly stretched 2p-1h configurations from targets of oxygen,[3] calcium,[4] and most recently strontium.[5] Each target isotope was chosen to have the highest filled neutron orbital correspond to an empty proton orbital. The configurations for the observed final states are (1d$_{5/2}$)^3, (1f$_{7/2}$)^3, and (1g$_{9/2}$)^3 having spins as large as 13/2$^+$, 19/2$^-$, and 25/2$^+$. respectively.

Representative spectra from the present work in the Zr region are shown in Fig. 1 (^{88}Sr was chosen as a target in this mass region because of the larger separation of discrete residual states). Our tentative identification of an observed state at 4.2 MeV in ^{89}Zr as the 25/2$^+$ state is based in part on the calculations of Brown.[6] Using shell model wave functions with a zero-range plane-wave approximation for the production process (a technique which gave striking agreement with excitation spectra and other systematics observed for various calcium isotope targets),[7] the 25/2$^+$ state was predicted by Brown to have an excitation of 4.1 MeV and to be weaker in the forward hemisphere than a neighboring 21/2$^+$ state at 3.7 MeV. Near 90° and in the backward hemisphere generally, the 25/2$^+$ was predicted to be the strongest state in the spectrum. These features are indeed borne out as exhibited in the two spectra from the ^{88}Sr(p,π$^-$)^{89}Zr reaction (T$_p$ = 175 MeV; lab angles 45 and 90 degrees) displayed in Fig. 1. The fact that the cross section for the highest spin state stays large (relative to the lower spin
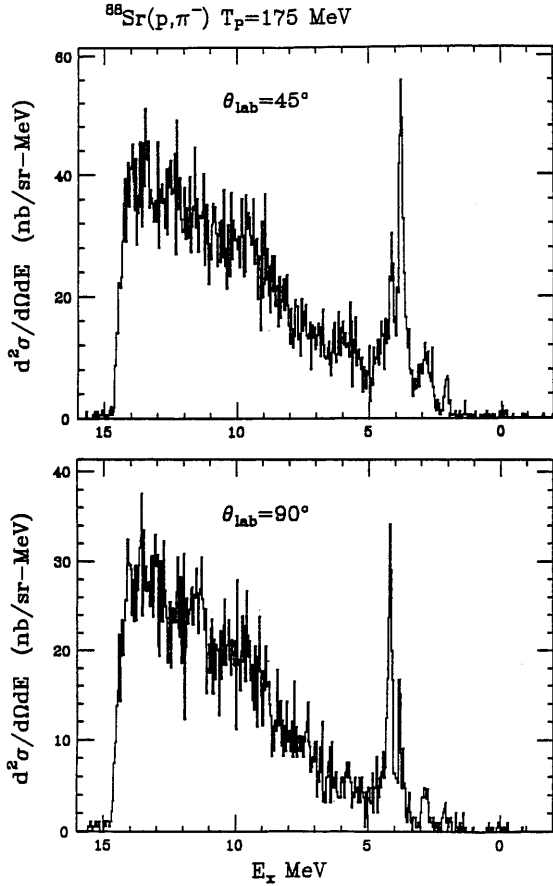
⁸⁸Sr(p,π⁻) Tₚ=175 MeV

Figure 1. Spectra for ^{88}Sr(p,π^-) at T_p = 175 MeV and two different lab angles (45 and 90 degrees) showing the dominance of the tentatively identified $25/2^+$ stretched state E_x = 4.2 MeV at the larger angles.

states) at the more backward angles is both expected from rather general momentum coupling arguments for these large total-L transfers, and in accord with observations of similar states in the calcium[4] region. This relative weakness of the stretched configuration at forward angles may be responsible in part for the lack of agreement between known stretched state excitation energies and measured average excitation energies for unresolved discrete states observed previously[1] in (p,π^-) at forward angles in the Zr region.

Remarkably, the analyzing power distributions (shown in Fig. 2) of the highest spin states observed

from the ^{18}O, ^{48}Ca, and ^{88}Sr target nuclei have been found to be quite similar, exhibiting a negative dip at forward angles, and crossing over at about 60° to generally positive analyzing powers at larger angles. This qualitative observation awaits explanation, but may have spectroscopic application as a universal signature of the stretched configuration.

In fact, armed with this possible analyzing power signature and the prediction (coupled with observation) that these high spin configurations stand out most clearly at the more backward angles, we plan to continue our studies to heavier target nuclei. In particular, we plan to look at ^{144}Sm and ^{208}Pb where we hope to observe states based on $(1h_{11/2})^3$ and $(1i_{13/2})^3$ 2p-1h configurations, respectively.[8] The high-spin
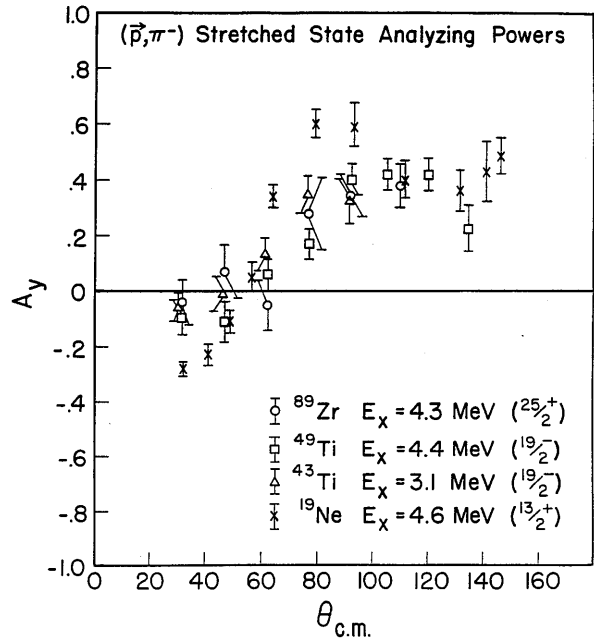

Figure 2. Analyzing power distributions for the 2p-1h stretched state configurations excited in (p,π^-) from the target nuclei ^{18}O (Ref. 3, T_p = 201), ^{42}Ca (Ref. 4, T_p = 205 MeV), ^{48}Ca (Ref. 4, T_p = 166 MeV), and the target used in the present study ^{88}Sr (Ref. 5, T_p = 175 MeV), showing an apparent universal signature. The $A_y(\theta)$ values plotted for the ^{42}Ca case are presented as the sum of an unresolved doublet at the stretched state excitation energy in the spectra.

stretched states for these two cases would be $31/2^-$ and $37/2^+$, estimated[6] to lie at $E_x \sim 4.6$ and 6.4 MeV, respectively, in ^{145}Gd and ^{209}Po.

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(p,π⁻) SPECTROSCOPY in the sd SHELL

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The potential usefulness of the (p,π⁻) reaction for nuclear spectroscopy results from two features of the reaction that have been inferred from recent IUCF experiments:[1,2]

    1) the dominance of a two-nucleon reaction mechanism (at least for certain transitions), and

    2) the preferential population of high-spin final states (because of the large momentum transfer).

Consequently, the reaction should be useful in identifying high-spin states having a simple 2p-1h configuration with respect to the target nucleus, which may not be easily seen or identified by other means.

The striking selectivity of the (p,π⁻) reaction for high-spin 2p-1h states was first observed for a number of targets in the C, Ca and Zr mass regions.[1] Recently, Brown et al.[3] have shown that the main features of the relative cross sections in the Ca region can be qualitatively understood within the context of the $(1f_{7/2})$ shell model, together with only general assumptions about the reaction mechanism. The spectra are dominated by an "ℓ-window" created on the lower side by the momentum mismatch in the reaction and on the higher side by the maximum angular momentum transfer available for three particles in the fp-shell.

A similar selectivity of the (p,π⁻) reaction has been observed[4] for sd-shell targets: ^{18}O and ^{26}Mg. The qualitative correspondence between some of the main features of the ^{18}O(p,π⁻)^{19}Ne and ^{26}Mg(p,π⁻)^{27}Si spectra and the full sd-shell model calculations of Wildenthal[5] is encouraging evidence that the (p,π⁻) reaction can provide useful spectroscopic information, and that further studies of the (p,π⁻) reaction on other sd-shell nuclei would be timely.

Fig. 1 shows the results of a preliminary survey of (p,π⁻) spectra from several Mg and Si isotopes. Further studies in the sd-shell are planned.