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^{7}Li($\vec{p}$,π^+)^{8}Li* at incident proton energies of 250, 354, and 489 MeV

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Differential cross sections and analyzing powers of the ^{7}Li($\vec{p}$,π^+) reaction at $T_p = 250$, 354, and 489 MeV leading to three excited states of ^{8}Li are presented and are compared with previously published 200 MeV data. The differential cross sections at constant four-momentum transfer for two of the states exhibit an enhancement at approximately the Δ_{1232} invariant mass, and shapes of the analyzing power angular distributions for these states exhibit a characteristic $\vec{p}p \rightarrow d\pi^+$ signature. Quite different dependences are observed for the third state.

Despite 15 years of extensive experimental and theoretical work,[1–4] nuclear pion production remains a central problem in intermediate energy nuclear physics that needs to be better understood if one is to develop a systematic understanding of high-momentum transfer processes in general and if one is to have any hope of identifying quark effects in such processes. Theoretical calculations of nuclear (p,π^+) reactions have had only limited success in describing experimental data. It is hoped that systematic experimental data over a large range of target nuclei and incident proton energies will help disentangle nuclear structure and reaction mechanism effects. Data near 350 MeV are especially important in this regard because the Δ_{1232} resonance should dominate the (p,π^+) reaction in this energy range and simplify the theoretical calculations.

A key objective in investigations of the (p,π^+) reaction has been the separation of nuclear structure effects from those of the reaction mechanism. Recent measurements of (p,π^+) differential cross sections and analyzing powers for transitions to many different final states at several bombarding energies[5–7] are beginning to delineate important systematics of the nuclear (p,π^+) reaction. Of particular importance in this regard are investigations in the Δ_{1232} resonance region where the signatures of the Δ_{1232} should be the least ambiguous. As an extension of this effort, we have studied the ^{7}Li(p,π^+)^{8}Li* reaction with polarized proton beams of 250, 354, and 489 MeV, which covers the energy range near the invariant mass of the Δ_{1232}. A simple calculation shows that the peak of the Δ_{1232} resonance would occur at $T_p = 343$ MeV if the beam proton and ^{7}Li target combine to form a mass 8 nucleus with one nucleon excited to a mass of 1232 MeV. To aid in understanding the energy dependence of these reactions, we compare our results to recent 200 MeV data from the Indiana University Cyclotron Facility (IUCF).[8]

The experiment was performed with the medium resolution spectrometer (MRS) at TRIUMF using a polarized proton beam. The data were taken during a ^{16}O(p,π^+)^{17}O* experiment[9] in order to subtract off the background due to the ^{7}Li in the ^{7}Li^{16}OH target. At 250 and 354 MeV bombarding energies and forward angles, states from ^{7}Li(p,π^+)^{8}Li* reaction overlapped discrete states from the ^{16}O(p,π^+)^{17}O* reaction, and the data presented here were taken with a 208 mg/cm^2 thick metallic ^{7}Li target. Elsewhere, states from the ^{7}Li(p,π^+)^{8}Li* reaction occurred at low pion momentum in the continuum region of the ^{16}O(p,π^+)^{17}O* reaction, and the data presented here were taken with a 100 mg/cm^2 thick LiOH target. The experimental techniques are discussed in detail elsewhere.[7,9]

The spectrometer acceptance was calibrated at 489 MeV using the pp$\rightarrow$dπ^+ reaction, whose cross section is known to a high precision;[10] the proton energy was chosen so that pions from this reaction would have approximately the same momentum as pions from the ^{7}Li(p,π^+)^{8}Li reaction at 354 MeV. The effective solid angle of the spectrometer, determined by this method, was 2.8 msr, and compares with the 3.0 msr geometric solid angle of the MRS spectrometer. A systematic uncertainty of $\pm 7\%$ and a relative uncertainty of $\pm 17\%$ are assigned to the cross sections measured in this experiment. A sample pion spectrum taken with the pure ^{7}Li

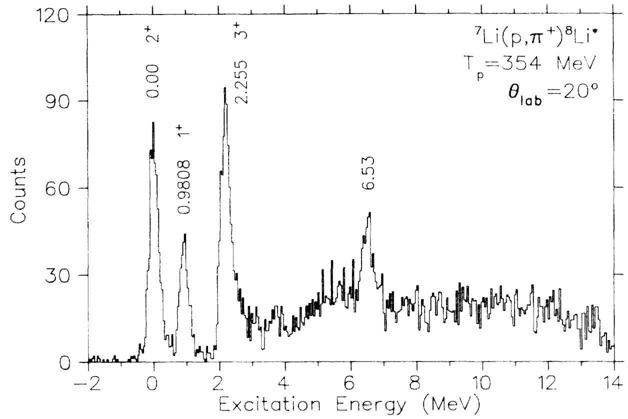

FIG. 1. Pion energy spectrum after solid angle, energy loss, time of flight, trajectory, and target beam spot cuts have been applied. The energy resolution is approximately 250 keV.

target is shown in Fig. 1.

The differential cross sections and analyzing powers for the reactions leading to the first three excited states of ^{8}Li at bombarding energies of 200, 250, 354, and 489 MeV are presented in Figs. 2–4. The results in these figures are plotted versus the relativistically invariant Mandelstam variable t, which is the square of the four-momentum transfer. As can be seen, there are similarities between Figs. 2 and 3. The differential cross sections for both states rise with energy from 200 MeV to approximately the Δ_{1232} invariant mass at 354 MeV, and then level off. This type of energy dependence at a constant four-momentum transfer has been noted many times before in (p,π^+) reactions,[7,9,15,16] and is similar to that exhibited by the pp$\rightarrow$dπ^+ reaction. For the latter case, however, the differential cross section slowly decreases with energy above the Δ_{1232} mass, while the differential cross sections shown in Figs. 2 and 3 are practically the same at 354 and 489 MeV. This behavior is probably due to contributions from the elementary pp$\rightarrow$pnπ^+ process, whose cross section levels off at energies above the Δ_{1232} resonance.[17]

The analyzing powers shown in Figs. 2 and 3 are also very similar to each other and to those of the elementary $\vec{\text{p}}$p$\rightarrow$dπ^+ reaction at equivalent center of mass energy and four-momentum transfer, which are shown by the curves in Fig. 3. Although this $\vec{\text{p}}$p$\rightarrow$dπ^+ type of analyzing power distribution is well known for nuclear ($\vec{\text{p}}$,π^+) reactions,[18] the similarities shown in Fig. 3 are especially striking. On heavier target nuclei, the ($\vec{\text{p}}$,π^+) reaction has analyzing powers which are larger in magnitude than those of the $\vec{\text{p}}$p$\rightarrow$dπ^+ reaction.[9] The greater similarities between the $\vec{\text{p}}$p$\rightarrow$dπ^+ and ^{7}Li($\vec{\text{p}}$,π^+)^{8}Li$^*_{2.255}$ analyzing powers over a large energy range may be due to smaller distortion effects for this light target nucleus. Recent analyzing power measurements of the $\vec{\text{p}}$d$\rightarrow$tπ^+ reaction[19] are also very similar to those of the $\vec{\text{p}}$p$\rightarrow$dπ^+ reaction. The $\vec{\text{p}}$p$\rightarrow$dπ^+ curve for an effective proton energy of 489 MeV is not shown in Fig. 3 for the sake of clarity; it is quite flat and positive with

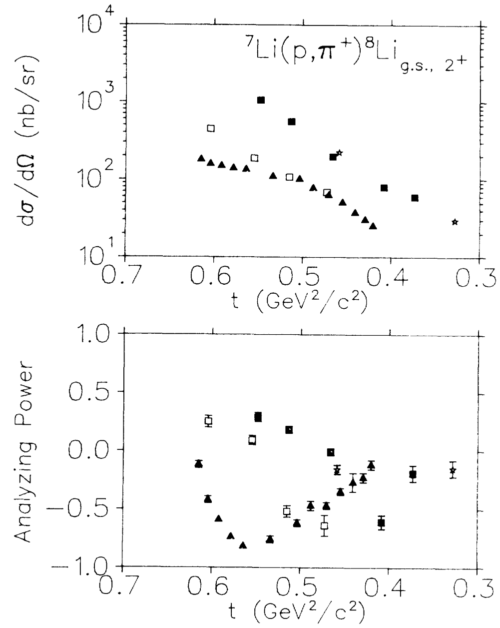

FIG. 2. Differential cross sections and analyzing powers for the ^{7}Li($\vec{\text{p}}$,π^+)^{8}Li$_{\text{g.s.}}$ reaction. Plotting symbols indicate the incoming proton energy and source of data as follows: ▲, 200 MeV (Ref. 8); □, 250 MeV (this work); ■, 354 MeV (this work); ☆, 489 MeV (this work).

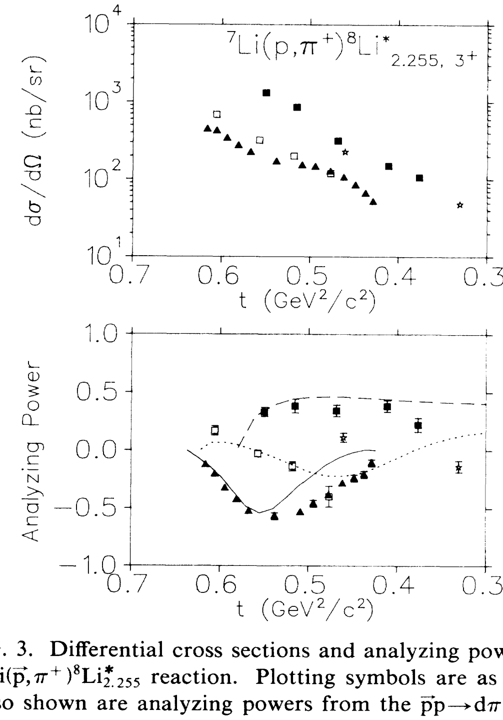

FIG. 3. Differential cross sections and analyzing powers for the ^{7}Li($\vec{\text{p}}$,π^+)^{8}Li$^*_{2.255}$ reaction. Plotting symbols are as in Fig. 2. Also shown are analyzing powers from the $\vec{\text{p}}$p$\rightarrow$dπ^+ reaction (Refs. 10–14) transformed to the nuclear kinematical frame at equivalent center of mass energy and four-momentum transfer. The solid line indicates the $\vec{\text{p}}$p$\rightarrow$dπ^+ analyzing power at 200 MeV, the dotted line at 250 MeV, and the dashed line at 354 MeV.

a magnitude of approximately 0.25. The analyzing powers shown in Fig. 2 are similar to those of Fig. 3, except that the dips in the 200 and 250 MeV data are more pronounced, and the 354 MeV data show a deep dip near $t = 0.4\ \mathrm{GeV}^2/c^2$.

The differential cross sections shown in Fig. 4 exhibit an enhancement at the Δ_{1232} invariant mass only at small momentum transfers ($t > 0.55\ \mathrm{GeV}^2/c^2$). At smaller t values the 200 MeV differential cross sections are much larger than those at 250 MeV, but smaller than those at 354 MeV. This energy dependence at small t is similar to that observed previously for (p,π^+) transitions on heavier target nuclei[7,9] in transitions to selected nuclear states for which the differential cross section exhibited a pronounced large-angle peak at low energies. Although the 200 MeV data[8] shown in Fig. 4 do not exhibit a large angle peak, the differential cross sections do not fall as rapidly at large angles as they do at 200 MeV in Figs. 2 and 3. It is not understood what feature of the nuclear structure is responsible for these effects.

Although at 200 MeV the analyzing powers for the transitions to all three final states are very similar, at higher energy each state portrays an individual character. There is a general trend, however, for the analyzing powers of all three states become more positive as the incoming proton energy increases from 200 to 354 MeV. This is also observed[9] for the $^{16}O(\vec{p},\pi^+)^{17}O^*$ reaction and appears to be a systematic feature of nuclear $(\vec{p},\pi^+)$ reactions. The $\vec{p}p \rightarrow d\pi^+$ analyzing powers also exhibit a similar trend (see Fig. 3).

The $^8Li_{g.s.}$ and $^8Li^*_{2.255}$ states are believed[8] to have the same dominant configuration $[(\pi^1 p_{3/2})(\nu^1 p_{3/2})^3]$. This may explain why these two states display such similar differential cross section and analyzing power angular distributions and energy dependences. The $^8Li^*_{2.255}$ state contains a small (24%) admixture of a two-particle–one-hole $[(\pi^1 p_{3/2})(\nu^1 p_{1/2})^2(\nu^1 p_{3/2})]$ configuration (with respect to the target ^7Li nucleus) which can be populated only by two nucleon or higher-order mechanisms. This may enhance the $NN \rightarrow NN\pi^+$ contribution to this transition and cause the analyzing power angular distributions shown in Fig. 3 to more closely resemble the $pp \rightarrow d\pi^+$ curves than do the distributions shown in Fig. 2. The $^8Li^*_{0.9808}$ state has a predominant $[(\pi^1 p_{3/2})(\nu^1 p_{1/2})(\nu^1 p_{3/2})^2]$ configuration.[8] It is not understood how this causes the different energy dependences shown in Fig. 4.

The nuclear structure of the 6.53 MeV excited state of $^8Li^*$ also causes some interesting behavior. Although this state is clearly visible in Fig. 1, there is no similarly populated sharp peak corresponding to its isospin analog state in previously published $^7Li(p,\pi^-)^8B^*$ spectra.[20,21]

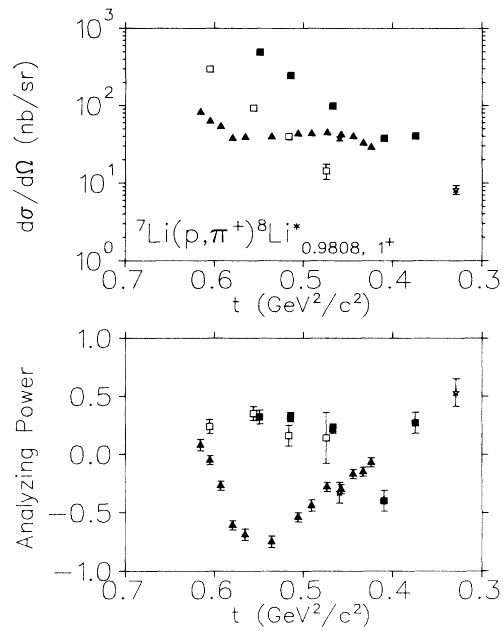

FIG. 4. Differential cross sections and analyzing powers for the $^7Li(\vec{p},\pi^+)^8Li^*_{0.9808}$ reaction. Plotting symbols are as in Fig. 2.

In summary, we have obtained data for the $^7Li(\vec{p},\pi^+)$ reaction leading to three final states of $^8Li^*$ at proton energies of 250, 354, and 489 MeV. The differential cross sections for two final states exhibit a maximum near the invariant mass of the Δ_{1232}. The analyzing power angular distributions for two states are similar to each other and to those of the $\vec{p}p \rightarrow d\pi^+$ reaction. For the third state (0.98 MeV, 1^+), both the differential cross sections and analyzing powers have a different energy dependence. This is presumed to be a nuclear structure effect.

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