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HIGH RESOLUTION STUDIES OF THE (p,π^+) REACTION ON 1p SHELL NUCLEI AT Ep=200 MeV

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It was shown by Dahlgren et al.[1] in one of the early Uppsala papers on nuclear pion production near threshold that the $^{12}C(p,\pi^+)^{13}C$ reaction produces final states of complicated structure just as strongly as states that can be reached by the direct transfer of a neutron. This is illustrated by the upper spectrum shown in Fig. 1, which was taken recently at IUCF with an overall energy resolution of 170 keV. The fact that the $1p_{1/2}$, $2s_{1/2}$ and $1d_{5/2}$ single-particle states at 0.0, 3.09 and 3.85 MeV, respectively, and the two particle-one hole states at 3.68, 6.86 and 9.50 MeV are populated about equally provided early evidence in support of a two-nucleon[2] or multistep[3] reaction mechanism.

Recent high resoultion studies of the (p,π^+) reaction on other targets in the p-shell indicate that strong production of core-excited states may be the exception rather than the rule. Figure 2 (top) shows a $^{10}B(p,\pi^+)^{11}B$ spectrum taken at IUCF with an overall energy resolution of 210 keV. The five low-lying states of odd-parity in ^{11}B are believed to arise mainly from configurations comprised of $p_{3/2}$ and $p_{1/2}$ nucleons and are well described by the shell model based on the intermediate coupling scheme.[4] The states at $0.00(3/2^-)$ and $4.44(5/2^-)$ MeV which are strongly excited in the (p,π^+) reaction also are populated strongly in the (d,p) reaction and have the largest single-particle spectroscopic factors. The $2.14(1/2^-)$ state, which is forbidden by

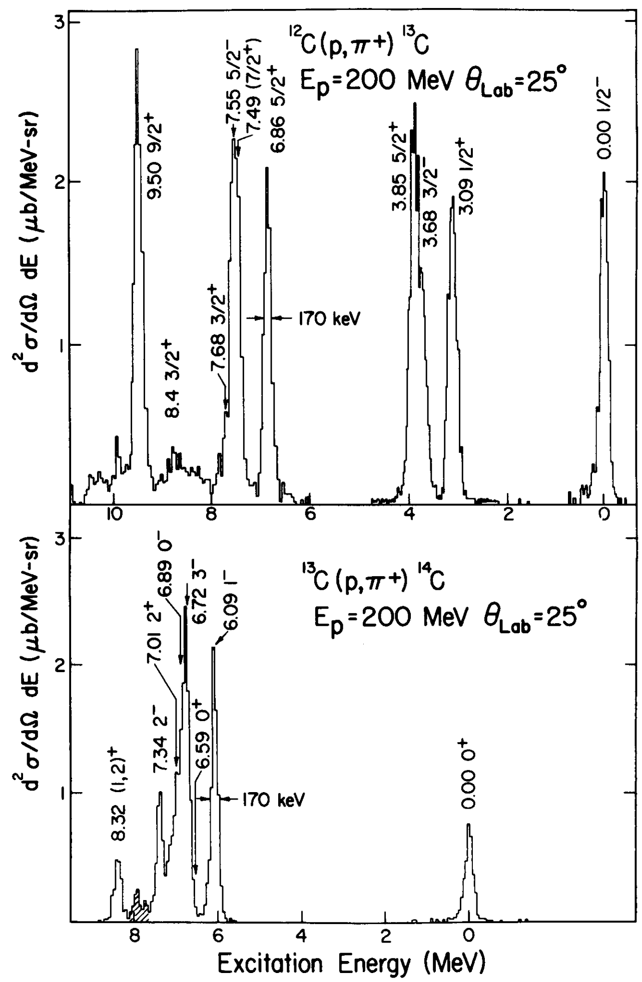

Figure 1. Pion energy spectra from the reactions $^{12}C(p,\pi^+)^{13}C$ and $^{13}C(p,\pi^+)^{14}C$ at T_p=200 MeV and $\theta_\pi(lab) = 25^o$.

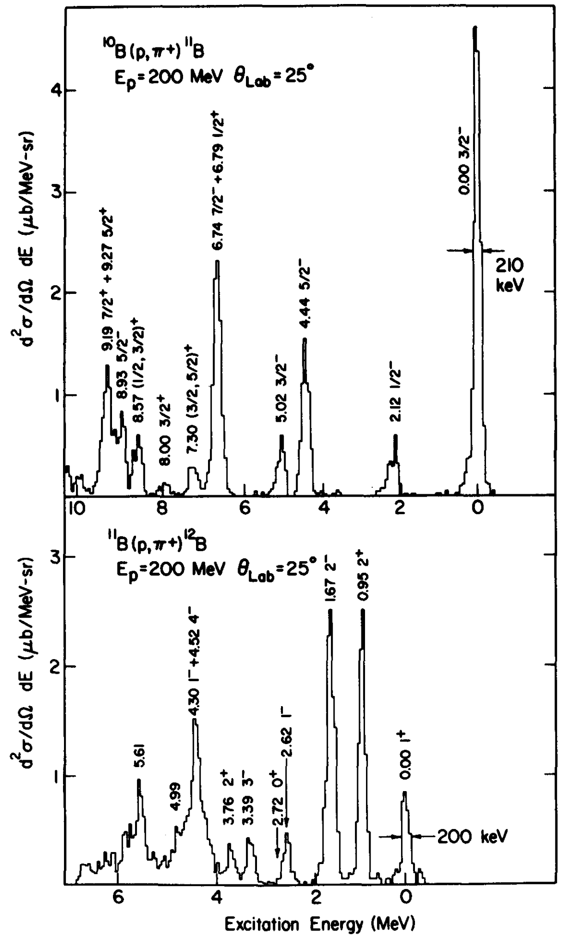

Figure 2. Pion energy spectra from the reactions $^{10}B(p,\pi^+)^{11}B$ and $^{11}B(p,\pi^+)^{12}B$ at T_p=200 MeV and θ_π(lab)=25°.

a one-step mechanism, and the 5.02($3/2^-$) state, which is predicted by the intermediate-coupling model to have little overlap with the ^{10}B ground state, are both populated weakly in the (p,π^+) and (d,p) reactions. The three even parity states at 7.30, 8.00 and 8.57 MeV are characterized by weak (d,p) intensities suggestive of highly mixed configurations. These states are also populated weakly in the (p,π^+) reaction. The two states of even parity near 9 MeV have very large (d,p) stripping amplitudes characteristic of direct neutron capture into the 2s or 1d shell without appreciable excitation of the ^{10}B core. Transitions to these states, as well as the 6.7 MeV doublet state (presumably mainly the 6.74($7/2^-$) single-particle state), are enhanced in the (p,π^+) reaction but to a lesser degree.

Because of the large momentum transfer in the (p,π^+) reaction, transitions to states of high angular momentum are expected to be preferred. This may account for some of the enhancements seen in the $^{10}B(p,\pi^+)^{11}B$ reaction but cannot explain the relative intensities of transitions to the two $3/2^-$ states at 0.0 and 5.02 MeV nor the strong suppression of transitions to the states at 2.14, 7.3, 8.0 and 8.57 MeV.

A similar selectivity is exhibited by the $^{11}B(p,\pi^+)$ ^{12}B reaction (Fig. 2, bottom). In this case, states at 0.0 (1^+), 0.95 (2^+), 1.67 (2^-) and 2.62 (1^-) MeV, which can be formed by coupling a $p_{1/2}$ or $2s_{1/2}$ neutron to the ^{11}B ground state, are populated strongly, whereas the 2.72 MeV (0^+) state, which requires recoupling of core nucleons together with the transfer of a neutron, is populated weakly. A preference for single-particle final states is also seen in the $^{13}C(p,\pi^+)^{14}C$ reaction (Fig. 1, bottom); for example, the 0^+ single-particle ground state is excited strongly compared to the 0^+ core-excited state at 6.59 MeV.

In short, for the (p,π^+) reaction on ^{10}B, ^{11}B and ^{13}C targets at 200 MeV bombarding energy, final states that can be reached by the simple transfer of a neutron tend to be favored compared to states of more complicated structure. This is suggestive of a one-step reaction mechanism. A quite different behavior is observed for the $^{12}C(p,\pi^+)^{13}C$ reaction, which populates single-particle and 2p-1h final states about equally, demonstrating the multi-nucleon aspect of the production process for this particular case (which seems to be an exception in the 1p-shell).

The interpretation of (p,π^+) data is difficult because of the unknown way in which the reaction dynamics and nuclear structure effects are interrelated, and also because there appear to be several reaction mechanisms with possibly different energy- and A-dependences. The high resolution spectra shown here indicate that the dominant reaction mechanism is determined to a certain extent by the nuclear structure changes that occur during the reaction, and that it may be possible to use nuclear structure effects to isolate different aspects of the reaction process.

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ENERGY DEPENDENCE OF THE $^{12}C(p,\pi^+)^{13}C^*$ REACTION TO 2p-1h FINAL STATES

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The reactions $^{12}C(p,\pi^+)^{13}C^*$ leading to specific final states have been studied with proton beams in the energy range 166 to 200 MeV. The aim of this work is to shed light on the mechanism of the (p,π^+) reaction by comparing the energy dependence of transitions to 2p-1h states at E_X = 3.68(3/2$^-$), 6.86(5/2$^+$) and 9.50 (9/2$^+$) MeV with that of transitions to single-particle states at 0.0(1/2$^-$), 3.09(1/2$^+$) and 3.85(5/2$^+$) MeV. Angular distributions at several energies have been measured using the QDDM and $D\bar{D}$ pion spectrographs. The close-lying states at 3.68 and 3.85 MeV were cleanly resolved with the QDDM spectrograph (see Fig. 1), and separate angular distributions for these states were obtained for the first time. The measured angular distributions of the differential cross sections are shown in Fig. 2 together with 185 MeV Uppsala data.

A comparison of the angular distributions for transitions to the two 5/2$^+$ states (the single-particle ($1d_{5/2}$) state at 3.85 MeV and the core-excited ($1d_{5/2} + 2s_{1/2} \otimes 1p_{3/2}^{-1}\, 1p_{1/2}$) state at 6.86 MeV) indicates that, though the shapes of the angular distributions are similar except for a displacement in position of the minimum, the magnitudes and energy dependences of the total cross sections are quite different (Fig. 3). The main component of the 3.68 MeV

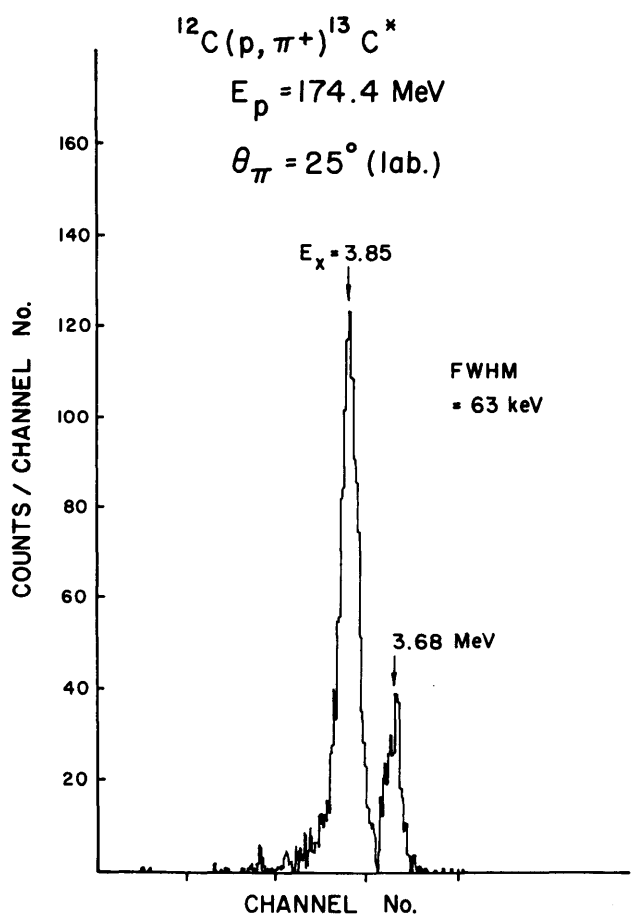

Figure 1. The spectrum for doublet state in $^{12}C(p,\pi^+)^{13}C$ reaction obtained with the QDDM magnetic spectrograph.