

state is the $(1p_{1/2} \otimes 1p_{3/2}^{-1} 1p_{1/2})$ configuration. The different slope of the excitation functions for the 3.68 and 6.86 MeV 2p-1h states compared to that for the 3.85 MeV single-particle state indicates a difference in the reaction mechanism for production of 2p-1h and single-particle final states. The steeper slope for the 2p-1h final states suggests a multistep mechanism involving core excitation by the outgoing pion. On the other hand, the slope of the excitation function for the 9.50 MeV state, which is supposed to be a $(1d_{5/2} \otimes 1p_{3/2}^{-1} 1p_{1/2})$ stretched configuration, appears to be similar to that for the 3.85 MeV single-particle state. The enhancement of transitions to the 9.50 MeV state is probably due to its high spin, which is favored because of the large angular momentum mismatch in the (p, π^+) reaction.

Figure 3. Excitation Function for total cross sections in the $^{12}\text{C}(p, \pi^+)^{13}\text{C}^*$ reactions.

POSITIVE-PION PRODUCTION BY 149-166 MeV PROTONS ON ^{16}O AND ^{28}Si

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Extensive data on the energy dependence of the (p, π^+) reaction exists only for transitions leading to the ^{11}B and ^{41}Ca ground states,¹ which involve the $1p_{3/2}$ and $1f_{7/2}$ neutron orbitals, respectively. Similar data for other cases involving different orbitals would be useful in determining whether the main features of the (p, π^+) angular distributions are due to nuclear structure or the reaction mechanism. It would also be useful to study the energy dependence of transitions to several different final states of the same nucleus, since the pion and proton distortions would be about the same in this case, and such measurements would strongly constrain the

pion and proton optical potentials in DWBA calculations.

Motivated by the above considerations, additional energy dependence studies of the (p, π^+) reaction near threshold have been carried out with ^{16}O and ^{28}Si targets. Angular distributions have been obtained for transitions to the ^{17}O ground state ($5/2^+$) at 154, 157 and 165 MeV bombarding energy and the 0.87 MeV ($1/2^+$) state at 157 MeV; these two states are known to be good single particle states involving the $1d_{5/2}$ and $2s_{1/2}$ neutron orbitals, respectively. For the $^{28}\text{Si}(p, \pi^+)^{29}\text{Si}$ reaction, 149 and 160 MeV protons were used to obtain angular distributions

for the 0.0, 1.27, 2.03 and 3.62 MeV states, for which $J^\pi = 1/2^+, 3/2^+, 5/2^+$ and $7/2^-$, respectively. These states are generally more complicated in structure and typically have small single particle strengths, except for the 1.27 MeV state, which has a large $1d_{3/2}$ single particle component. The 0.0, 2.03 and 3.62 MeV states have some single particle strengths involving the $2s_{1/2}$, $1d_{5/2}$ and $1f_{7/2}$ orbitals, respectively. The measurements at 149, 154 and 157 MeV were made with the DD spectrometer,² which was designed

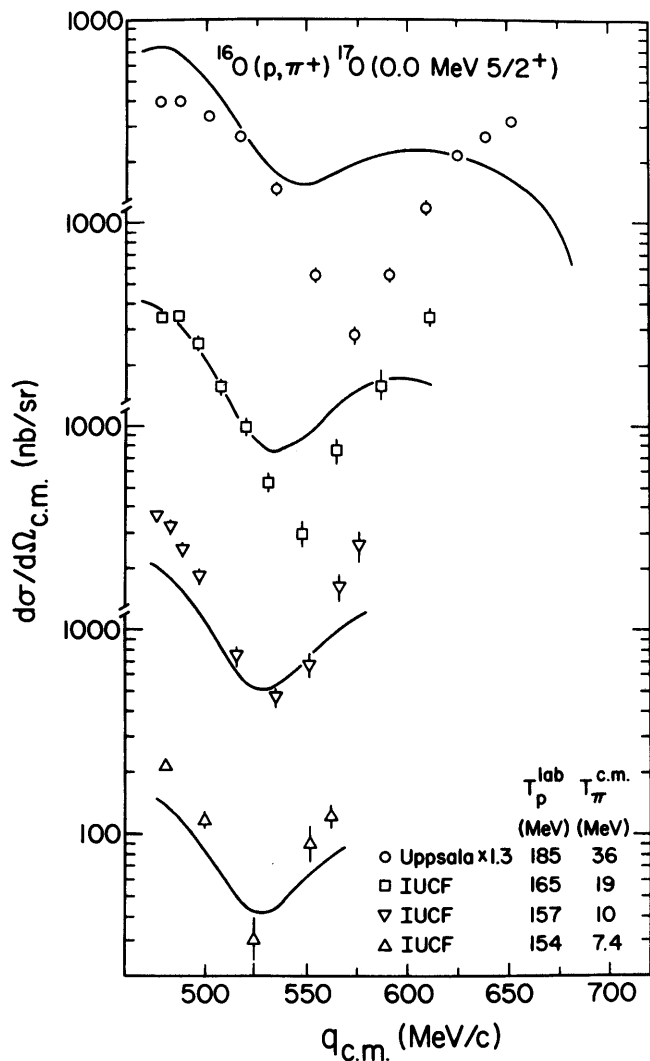


Figure 1. The $^{16}\text{O}(p,\pi^+)^{17}\text{O}(0.0 \text{ MeV } 5/2^+)$ differential cross sections at four energies plotted as a function of momentum transfer. The Uppsala results in this figure and all the succeeding figures are taken from Ref. 4. The curves are the results of DWBA calculations using the model of Ref. 5.

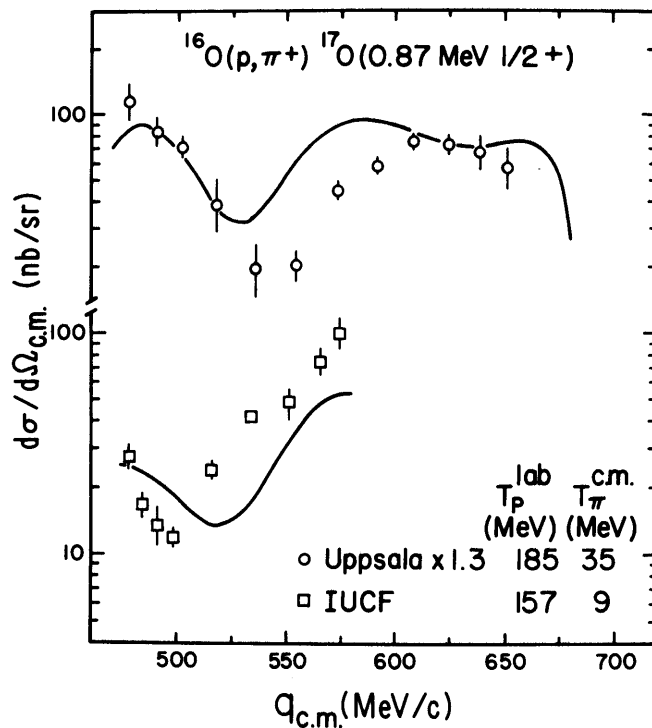


Figure 2. The $^{16}\text{O}(p,\pi^+)^{17}\text{O}(0.87 \text{ MeV } 1/2^+)$ differential cross sections at two energies.

to measure pions over an energy range of 5-13 MeV. For the 160-165 MeV measurements, the QDDM spectrometer was employed.³

The results of the $^{16}\text{O}(p,\pi^+)^{17}\text{O}$ and $^{28}\text{Si}(p,\pi^+)^{29}\text{Si}$ measurements are shown in Figs. 1-6, where the differential cross sections are plotted as a function of the center-of-mass momentum transfer q in units of MeV/c (typical range of pion angles is $20^\circ \leq \theta_\pi^{\text{lab}} \leq 150^\circ$). The error bars are statistical only; errors in the absolute cross sections are estimated to be $\pm 15\%$. Also included at the top of each figure are the Uppsala⁴ differential cross sections obtained at a bombarding energy of 185 MeV. The ^{16}O and ^{28}Si Uppsala cross sections have been multiplied by factors of 1.3 and 1.6, respectively, for normalization to the IUCF results. The combined IUCF-Uppsala measurements cover a range of pion energies from 7 to 36 MeV in ^{17}O and 7-45 MeV in ^{29}Si .

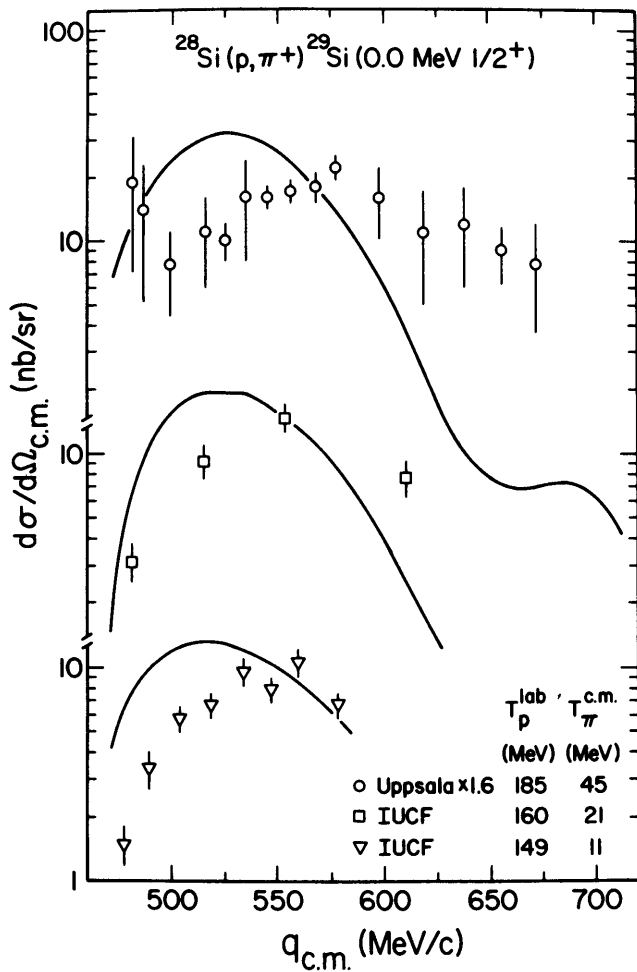


Figure 3. The $^{28}\text{Si}(p,\pi^+)^{29}\text{Si}(0.0 \text{ MeV } 1/2^+)$ differential cross sections at three energies. The curves in this figure and figures 4, 5 and 6 are the results of DWBA calculations using the model of Ref. 5. For this figure, the curves have been multiplied by a factor of 0.33.

The most prominent energy dependent feature of the ^{17}O and ^{29}Si angular distributions is the shift of the minimum to larger values of momentum transfer with increasing pion momentum p_π . This feature was also observed for the (p,π^+) transition to the ^{41}Ca ground state,¹ where it was observed that the momentum transfer at the minimum q_{min} varied linearly with p_π according to $dq_{\text{min}}/dp_\pi = 0.82 \pm 0.09$. Assuming a linear dependence for the final states in ^{17}O and ^{29}Si , least squares fits to the data yield values which are consistent with the ^{41}Ca results.

Several other features of the combined data in

Figs. 1-6 and ^{41}Ca are as follows:

- 1) For final states involving the same neutron orbital in different nuclei, q_{min} is largest for the nucleus of smallest mass.
- 2) q_{min} depends explicitly on the final state produced in the residual nucleus.
- 3) The shapes of angular distributions for transitions to states which have the same spin and parity are similar.
- 4) The $^{28}\text{Si}(p,\pi^+)$ cross sections are smaller than those for ^{16}O and ^{40}Ca . This is not surprising if the stripping mechanism is important, because the single particle strengths in the ^{17}O and ^{41}Ca final states are much larger than those in ^{29}Si . An exception is the 1.27 MeV state in ^{29}Si , which has a large

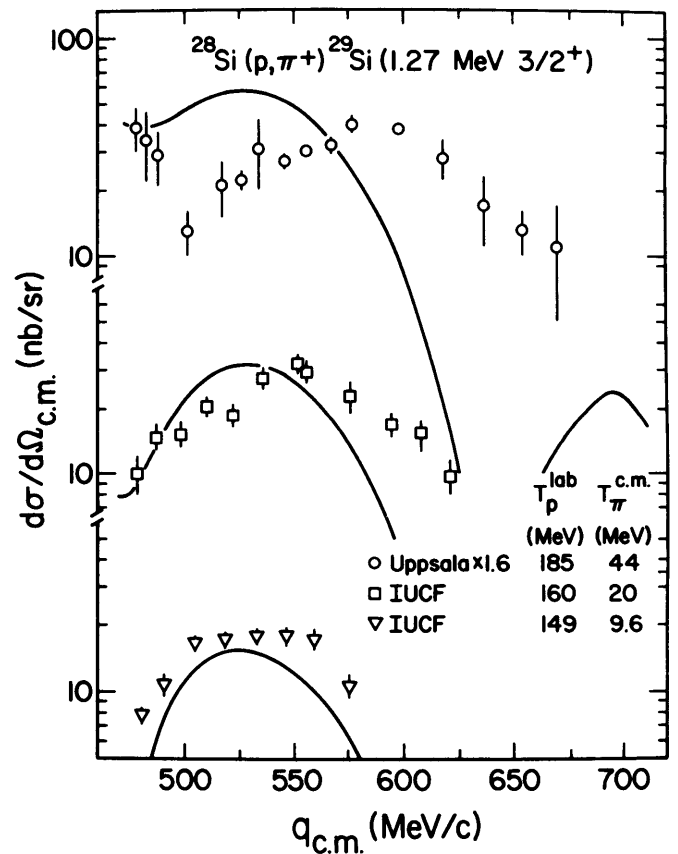


Figure 4. The $^{28}\text{Si}(p,\pi^+)^{29}\text{Si}(1.27 \text{ MeV } 3/2^+)$ differential cross sections at three energies. The $T_p=185 \text{ MeV}$ curve has been multiplied by a factor of 0.7.

$1d_{3/2}$ single particle component, but does not appear to have an enhanced cross section.

Also included in Figs. 1-6 are DWBA (pionic stripping) calculations.⁵ In the DWBA model, the proton is assumed to emit a pion and the resulting neutron is captured directly into an available single nucleon state. The calculations include both proton and pion distortions, a Laplacian-like pion nucleus potential with off-shell damping, and a neutron bound state calculated from a Woods-Saxon potential. In all the calculations, a spectroscopic factor of 1.0 was used. This should be a reasonable assumption for the ^{17}O ground and 0.87 MeV states, as well as the ^{29}Si 1.27 MeV state. However, transfer reaction

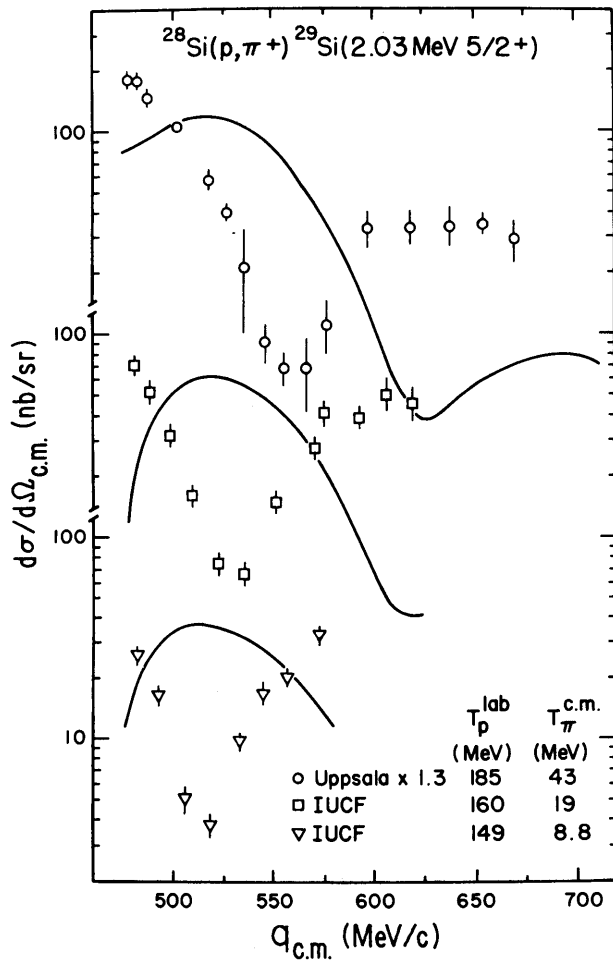


Figure 5. The $^{28}Si(p,\pi^+)^{29}Si(2.03\text{ MeV } 5/2^+)$ differential cross sections at three energies.

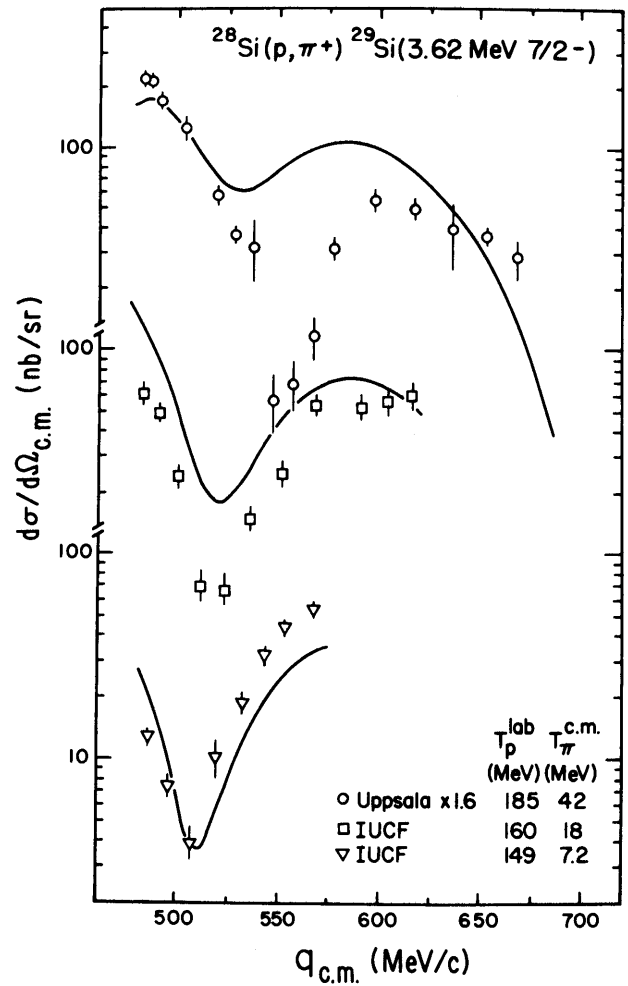


Figure 6. The $^{28}Si(p,\pi^+)^{29}Si(3.62\text{ MeV } 7/2^-)$ differential cross sections at three energies. The curves in this figure have been multiplied by a factor of 0.33.

measurements suggest the 0.0, 2.03 and 3.62 MeV states in ^{29}Si have small spectroscopic factors; using these spectroscopic factors would give calculated total cross sections for these states that differ from experiment approximately by factors of 3.0, 0.2 and 2.0, respectively. The calculations are very sensitive to the pion distortions and the parameters of the neutron potential.⁵

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COMPARISON OF (d,p) AND (p, π^+) REACTIONS ON ^{28}Si AT SIMILAR MOMENTUM TRANSFER

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With a view to compare and contrast the (d,p) stripping reaction with the (p, π^+) reaction, angular distribution measurements of $^{28}\text{Si}(p,\pi^+)^{29}\text{Si}$ cross sections ($E_p=191$ MeV) to several low-lying excited states in ^{29}Si were made. In addition, existing (d,p) angular distribution measurements at $E_d=76$ MeV were extended to larger angles in order to overlap the momentum transfer (up to $q\sim 600$ MeV/c) inherent to the (p, π^+) reaction. Of particular interest is a comparison of the (d,p) and (p, π^+) results for the relative population of states of the same J^π , but different single-particle spectroscopic strengths, in ^{29}Si : two $3/2^+$ states ($E_x=1.27$ and 2.43 MeV) and two $5/2^+$ states ($E_x=2.03$ and 3.07 MeV). Such a comparison should be sensitive primarily to differences in residual-state wave function components sampled by the two reactions. Other differences between the two reactions, e.g., in angular momentum coupling and matching, and in distortions of the incident and outgoing waves, should effectively cancel in the population ratios.

Spectra for the two reactions are shown, for nominal momentum transfer $q\sim 550$ MeV/c, in Fig. 1. The low-yield (p, π^+) and large-angle (d,p) data were obtained with a detection/identification system in the QDDM spectrograph focal plane similar to that used previously at IUCF for other charged pion production measurements¹. The (d,p) data ($5^\circ \leq \theta_L \leq 90^\circ$) were ob-

tained with a natural Si target ~ 6 mg/cm² thick. At angles larger than 65° , the 3.07 MeV $3/2^+$ state was contaminated by a contribution from the 5.28 MeV 3^- state of ^{30}Si (seen in Fig. 1a as a high- E_x shoulder). The 3.62 MeV $7/2^-$ state angular distribution, scaled to

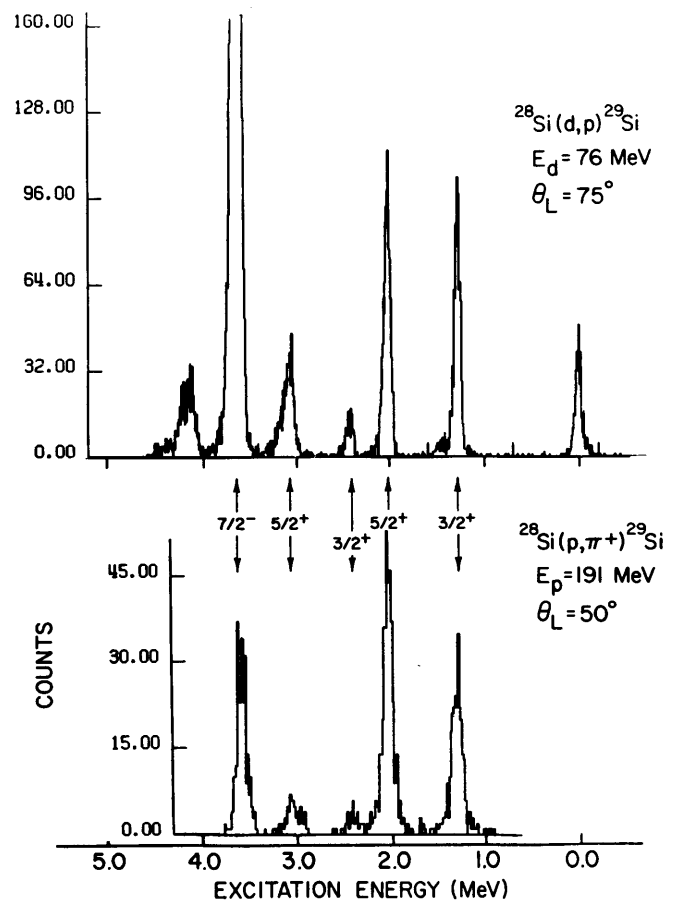


Figure 1. Comparison of (d,p) and (p, π^+) spectra from Si at a nominal momentum transfer $q\sim 550$ MeV/c. The location of the $3/2^+$ and $5/2^+$ states of interest in ^{29}Si are indicated by the arrows.