PION PRODUCTION

COULOMB EFFECTS IN THE $^3\text{He}(p,\pi^+)^4\text{He}$ AND $^3\text{He}(n,\pi^-)^4\text{He}$ REACTIONS

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In two previous publications$^{1,2}$, we have described in detail a microscopic model of proton-induced nuclear pion production and its application to the $^3\text{He}(p,\pi^+)^4\text{He}$ reaction at $T_{\text{lab}}^p = 178$ and 200 MeV ($T_{\text{cm}}^p = 10.5$ and 25.7 MeV, respectively). The model calculations described reasonably well the shapes of the differential cross section and analyzing power angular distributions but underestimated the magnitudes of the cross sections by a factor of three or more. This discrepancy in size between the calculated and measured cross sections is found to disappear when Coulomb effects are properly taken into account.

Our microscopic model of the $A(p,\pi)A+1$ reaction is based on mesonic and isobaric degrees of freedom and includes explicitly both the one-nucleon mechanism (ONM) and the resonant $p$-wave rescattering part of the two-nucleon mechanism (TNM). The TNM contribution is split up into a projectile-emission (PEM) piece, in which the pion is emitted by the projectile and rescattered from a target nucleon, and a target-emission (TEM) piece, in which the opposite occurs. Higher order processes are included through proton-nucleus and pion-nucleus optical-model distortions.

In our earlier work$^{1,2}$, we used what we called a "realistic" bound-state wave function (bswf) for the 1S state in Helium derived from the charge form factors obtained from electron-$^4\text{He}$ elastic scattering using a procedure described by Shepard et al.$^3$ Strictly speaking, the wave function thus obtained is a proton bswf. Originally, we assumed that the difference between a proton and a neutron 1S bswf in Helium would not produce significantly different results in $^3\text{He}(p,\pi^+)^4\text{He}$ calculations; however, the difference in normalization between measured $^3\text{He}(p,\pi^+)^4\text{He}$ cross sections$^4$ and equivalent time-reversed $^4\text{He}(\pi^+,p)^3\text{He}$ and charge-symmetric $^4\text{He}(\pi^-,n)^3\text{H}$ cross sections$^5,6$ in the near threshold region, lead us to redo the $^3\text{He}(p,\pi^+)^4\text{He}$ calculations at 178 and 200 MeV with both proton and neutron bswfs obtained from Hartee–Fock (HF) calculations for $^4\text{He}$. The results are shown in Fig. 1. The solid and dashed lines in the top two figures are the results of $^3\text{He}(p,\pi^+)^4\text{He}$ and $^3\text{H}(n,\pi^-)^4\text{He}$ calculations, respectively, made at center-of-mass energies of 3879 MeV (left) and 3895 MeV (right) using the same "realistic" proton bswf for both calculations. The small differences seen here are mainly due to Coulomb induced
Figure 1. Top: $^3\text{He}(p,\pi^+)^4\text{He}$ and $^3\text{H}(n,\pi^-)^4\text{He}$ calculations at center-of-mass energies of 3879 MeV (left) and 3895 MeV (right) using the same proton bound state wave function for both reactions. Bottom: The corresponding results using a neutron bound state wave function in the $^3\text{He}(p,\pi^+)^4\text{He}$ calculation and a proton bound state wave function in the $^3\text{H}(n,\pi^-)^4\text{He}$ calculation. The data are for the $^3\text{He}(p,\pi^+)^4\text{He}$ reaction (from ref. 4).
difference between the proton and neutron bswfs for the 1S-state in Helium produces differences in magnitude between the calculated cross sections for the $^3\text{He}(p,\pi^+)^4\text{He}$ and $^3\text{H}(n,\pi^-)^4\text{He}$ reactions of a factor of 2 to 3 in favor of the $(p,\pi^+)$ reaction. This explains in part the difference in magnitudes of the cross sections for the $^4\text{He}(\pi^-,n)^3\text{H}$ and $^4\text{He}(\pi^+,p)^3\text{He}$ reactions measured by Källne et al.\textsuperscript{5,6} In contrast to this rather strong Coulomb effect, the Coulomb effects on the nucleon and pion distorted waves have little effect on the calculated $^3\text{He}(p,\pi^+)^4\text{He}$ and $^3\text{H}(n,\pi^-)^4\text{He}$ cross sections.

Our present $^3\text{He}(p,\pi^+)^4\text{He}$ calculation at 178 MeV (Fig. 1, bottom) describes both the absolute magnitude of the differential cross section and the angular distributions of the cross section and analyzing power data quite well. At 200 MeV, the calculation gives the experimental cross section at forward angles and a reasonable description of the analyzing power data, but still underestimates the cross section data at larger angles. This is presumed to be due to the sensitive interference between the ONM and PEM amplitudes, which are comparable in magnitude at this energy (whereas the ONM amplitude dominates at 178 MeV). In view of the high sensitivity of the low-energy calculations to the proton and pion distortions, this delicate interference may amplify any inadequacy in the optical model approach to the initial and final state interactions for such a light system as Helium.