EVIDENCE FOR DEUTERON CLUSTERING IN $^7$Li FROM THE NONCOPLANAR $^7$Li(p,pd)$^3$He REACTION AT $E_p$=200 MeV

R.E. Warner and B.A. Vaughan
Oberlin College, Oberlin, Ohio 44074

D.L. Friesel, F. Schwandt, and J-Q. Yang
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

G. Caskey, A. Galonsky, and B. Remington
Michigan State University, East Lansing, Michigan 48824

A. Nadasen
University of Michigan, Dearborn, Michigan 48128

Even though a nucleus is well described by one clustering mode, other modes are not necessarily precluded since these modes do not constitute an orthonormal set of states; individual nucleons can belong to different cluster modes simultaneously. For instance, $^6$Li has both $\alpha+d$ and $\tau+t$ configurations of comparable amplitude. This raises the question of whether $^7$Li, long known to have a spectroscopic factor near unity for $\alpha+t$, might also exhibit significant $^5$He+d clustering.

To explore this possibility, measurements were made of the $^7$Li(p,pd) knockout reaction at 200 MeV. Data were taken for a coplanar geometry ($\Theta_p/\Theta_d=64^\circ/47.4^\circ$) permitting quasi-elastic scattering and for three nearby noncoplanar geometries. Each of the four energy-sharing spectra showed a broad peak characteristic of s-state deuteron knockout. A distorted wave analysis indicates a $d+^5$He spectroscopic factor $C_d$ of about unity, and a plane wave analysis comparing these to our $^6$Li(p,pd) data yields $C_d=0.8$.

A 22 mg/cm$^2$ $^7$Li target, mounted in air and sealed between 2.1 mg/cm$^2$ protective foils of Cu-Ni alloy, was bombarded with 200 MeV unpolarized protons. The intrinsic Ge detector telescopes, and their associated electronics, were nearly identical to those used to study the noncoplanar $^6$Li(p,pd) reactions. There was negligible contamination of the spectra by sequential decay of intermediate excited states of $^6$Li and $^3$He.

Predicted cross sections were obtained from the distorted wave impulse approximation (DWIA). Published nuclear optical potential parameters for the p$^7$Li, p$^6$Li, and d$^4$He systems were utilized. The two latter sets were crudely adapted to the p$^5$He and d$^5$He systems by multiplying their well depths by $\sqrt{4}$. We used the elastic p$^3$He cross sections measured at 198 MeV.

These calculations fitted the coplanar energy-sharing spectrum with a $C_d$ of 1.4; an unphysical result since $^7$Li has three nucleons outside the $\alpha$-particle core. Numerous other parameter sets gave the $C_d$'s as large as 2.2, but none smaller than 1.4.

The measured cross sections were integrated over a 25 MeV interval including the quasielastic peak, and are plotted vs. the noncoplanarity angle in Fig. 1. The DWIA (with $C_d=1.4$) substantially underpredicts the large-angle cross section, as it also does for $^6$Li(p,pd).

Reduction of the imaginary well depths was the only optical parameter variation which significantly reduced $C_d$. Eliminating the entrance-channel absorption reduced $C_d$ to 1.1. This may be partially justified since the p$^7$Li inelastic cross section may be largely breakup while, in the DWIA, the primary p+d interaction causes the quasi-elastic scattering.

Since the overprediction of $C_d$ by the DWIA may also result from the diffuseness of the unbound $^5$He
Figure 1. Cross sections for $^7$Li(p, pd) at 200 MeV, integrated over a 25 MeV deuteron energy range, vs. deuteron noncoplanarity angle. DWIA predictions are shown with and without entrance channel absorption, and with an added isotropic "background".

cluster, the tail of the cluster wave function was artificially enhanced by smoothly joining the Woods-Saxon interior function to an exponentially-decreasing exterior function. A 4 fm falloff radius for the latter function reduced $C_d$ to 0.9, but the predicted quasi-elastic peak (Fig. 2) became too narrow to fit the noncoplanar data.

The large $C_d$ and anomalous large-angle yield might result from other reaction mechanisms, not considered by the DWIA, whose yields are more nearly isotropic. A better fit to the data of Fig. 1 is obtained by adding a constant "background" of 100 $\mu$b/sr$^2$ to the DWIA prediction with $C_d=1$. But this procedure is questionable since, even at large $\phi$, the energy-sharing spectra show the broad peaks characteristic of quasielastic scattering.

Figure 2. Coplanar energy-sharing predictions for the standard DWIA and with cluster wavefunctions enhanced in the tail region.

$C_d$ was also estimated from the plane wave impulse approximation (PWIA). Distortion and absorption effects for the $^6,^7$Li(p, pd) reactions should be similar, so the PWIA should better predict the ratio of the ratio of the reaction cross sections than their individual values. By equating the measured and PWIA-predicted ratios of these reaction cross sections and taking $C_d=0.76$ for $^6$Li, we find $C_d=0.82$ for $^7$Li.

The FWHM of the momentum distribution for d+$^5$He clusters was estimated to be 140 MeV/c. Fig. 3 shows the result of taking the cross section to be proportional to the momentum probability (assumed Gaussian) and fitting the cross sections nearest the quasielastic peak, at each $\phi$. The fit to the $\phi=16^\circ$ (p=140 MeV/c) datum was ignored; studies of the $^6$Li(p, pd) reaction also show a discrepancy between
measured and predicted cross sections for such large momenta.

Figure 3. Measured cross sections vs. momentum-squared of the undetected cluster; both are taken at the quasi-elastic peak predicted by the DWIA.