MECHANISMS OF THE $^6Li(^6Li,2\alpha)\alpha$, $^6Li(^6Li,2\alpha)2d$, AND $^6Li(^6Li,2d)2\alpha$ REACTIONS AT 97.5 MeV

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The $^6Li(^6Li,2\alpha)\alpha$ reaction may proceed by either direct capture of a deuteron cluster in the ^6Li nucleus by the other ^6Li, with the α-cluster of the former acting as a spectator, or sequential decay of an intermediate excited ^8Be level. The separation in the coincidence energy spectra of groups pertaining to these two processes increases as the bombarding energy rises.

Studies[1] of this reaction at bombarding energies of 2 to 13 MeV were said to show the dominance of the single spectator process (SSP); however, because of kinematical ambiguities, much of the yield could instead have resulted[2] from sequential decay of the 2.94 and 11.4 MeV ^8Be levels. At 36 to 46 MeV, the SSP yield was never more than one third of that due to sequential decay;[2] even with the improved separation at this energy, extraction of the spectator peak was difficult.

We have now made measurements at 97.5 MeV at the Indiana University Cyclotron Facility. Coincidence α-α spectra were obtained with two 2-counter telescopes coplanar with, and at equal angles on opposite sides of the beam. Optimum conditions for the spectator process are at $\theta_1 = \theta_2 = 38°$, where the undetected α-particle may be left at rest in the laboratory. The spectrum, shown in Fig. 1, is well fitted by spectator model predictions[2] which assume that a harmonic oscillator potential binds the α- and d-clusters into an s-state. Sequential decay from the levels near 20 MeV is well separated from the spectator peak, and that

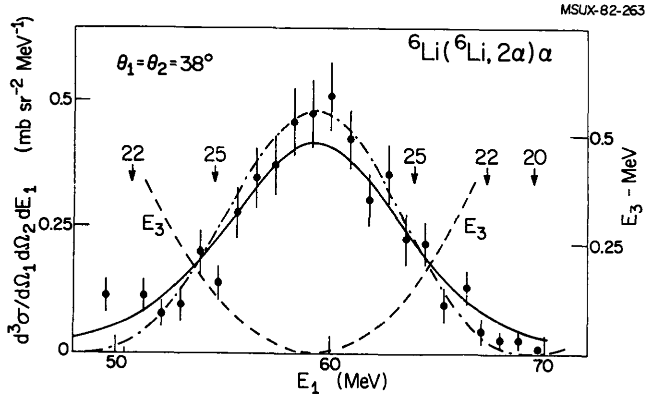

Figure 1. Absolute coincidence cross sections for the $^6Li(^6Li,2\alpha)\alpha$ reaction at 97.5 MeV, plotted versus the lab energy of one detected particle. Solid (dash-dot) curve shows normalized spectator model prediction utilizing Hulthen (harmonic oscillator) wave function. Dashed curve shows energy (right-hand scale) of undetected α-particle. Arrows show locations of possible enhancements due to sequential decay of ^8Be levels near 20, 22, and 25 MeV.

of lower-lying levels is still further removed. The SSP peak cross section, 4.5mb/sr^2, is three times the largest SSP cross section measured[2] near 40 MeV.

The cross section falls dramatically, as predicted by the spectator model, for detector angles $\theta_1 = \theta_2 = 42°$ and 44°; at these geometries, the minimum spectator energies are about 0.5 and 1 MeV, respectively. In Table I observed cross sections (integrated from E_α=48 to 71 MeV) are compared with spectator model predictions utilizing four cluster wave functions used[3] for interpreting $^6Li(^6Li,\alpha\alpha)dd$ data. All predictions are normalized to the 38° yield. Sequential decay contributions increase with increasing angle, and so the spectator cross sections would drop even more

Table I. Predicted and measured cross sections (mb/sr^2) for $^6Li(^6Li,\alpha\alpha)dd$ at 97.5 MeV.

Type	38.0°	42.0°	43.7°	46.4°
Harmonic Oscillator	4.45	0.32	0.52	0.23
Exterior square well	4.45	0.10	0.03	0.005
Tang-Wildermuth	4.45	1.28	0.25	0.003
Hulthen	4.45	0.89	0.04	0.03
Measured	4.45	0.36	0.18	0.41
$E_{3,min}$(MeV)	.001	0.49	1.08	2.63

sharply with angle if these contributions could be removed.

The 42° and 44° data sample the cluster momentum wave function $\Phi(p)$ at large momentum p, and the predictions are sensitive to the interaction. Thus, the Tang-Wildermuth and Hulthen wave functions significantly overpredict the yield. The harmonic oscillator or square well predictions may be best, depending upon the amount of sequential decay contamination. Experiments at 150 MeV or above would yield data free of sequential decay for spectator particle energies up to at least 5 MeV, and would sensitively test the cluster wave function $\Phi(p)$ for large p.

The $^6Li(^6Li,2\alpha)2d$ and $^6Li(^6Li,2d)2\alpha$ reactions were studied to search for double spectator pole (DSP) events. In such an event two nuclei, each containing two clusters, collide with one cluster from each nucleus retaining its initial momentum. Weak evidence[4] for DSP behavior in the $^3He(^3He,dd)pp$ reaction was reported, and $^2H(^2H,pp)nn$ data were interpreted[5] by a DSP model but later shown[6] to be better fitted by a double-final-state-interaction model. More recently anomalously sharp peaks were observed[3] in both α-α and d-d coincidence spectra from $^6Li + ^6Li$ double breakup at $E_0 \sim 40$ MeV, with their centers at those energies where the DSP is expected. Straightforward improvements[7] of the PWBA - DSP model — including symmetry under boson exchange, Coulomb cluster wave functions, deuteron structure, and a finite-range participant interaction potential — failed to change the predicted widths of these peaks, which typically were five times as great as those observed.

Figure 2 shows our α-α coincidence spectra from the $^6Li(^6Li,2\alpha)2d$ reaction at 97.5 MeV. The spectra are for $E_{\alpha1} = E_{\alpha2}$, i.e. from the total available phase space, a cut is taken along the 45° line in the $E_{\alpha1} = E_{\alpha2}$ plane. The detector angles are uncertain by about 1°, as was found while performing an energy calibration with the $^2H(^6Li,2\alpha)$ reaction. The DSP-model predictions have been shifted by amounts up to 2 MeV,

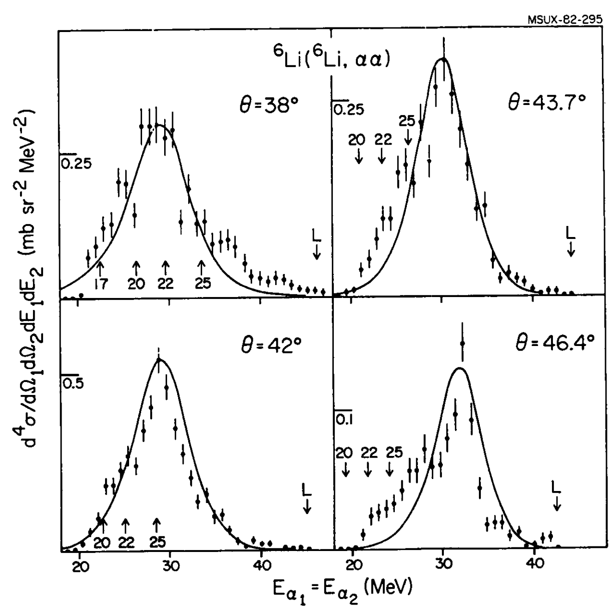

Figure 2. Measured α-α absolute coincidence cross sections for the $^6Li(^6Li,2\alpha)$ multibody final state, and predictions for the double spectator model using the Hulthen wave function. Numbered arrows indicate ^8Be sequential decay locations, and "L" shows the 4-body kinematic limit.

to align them with the observed peaks. Such shifts are commensurate with the detector angle uncertainty.

At this bombarding energy, the widths and shapes of the observed peaks are consistent with the predictions of the DSP model. Moreover, these peaks contain virtually all the yield between the detector threshold energy (~20 MeV) and the four-body kinematic limit (~45 MeV). Their strengths are comparable to those observed[3] at Chalk River; their widths are about 10 times and their amplitudes about 0.1 times, as great as in the 40 MeV data.

Cross sections for d-d quasi-elastic scattering (QFS) were found to be much smaller than those for α-α QFS, and there was less evidence for peaks having the DSP shape. This probably reflects a dominance of d+d breakup over elastic scattering at these bombarding energies.

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