*Research supported in part by the National Science Foundation.

[1]E. O. Alt, P. Grassberger, and W. Sandhas, Phys. Rev. C 1, 85 (1970), and references contained therein.
[2]R. D. Amado, Phys. Rev. 132, 485 (1963).
[3]This model is related to one suggested in the Lee model by J. Bronzan, Phys. Rev. 139, B751 (1965).
[4]S. Watanabe, Nucl. Phys. 8, 484 (1958).
[5]R. C. Johnson and P. J. R. Soper, Phys. Rev. C 1, 976 (1970).

PHYSICAL REVIEW C VOLUME 6, NUMBER 4 OCTOBER 1972

Isospin Impurity of the 4.57-MeV State in ^{6}Li†

R. M. DeVries,* Ivo Slaus,‡ and Jules W. Sunier
University of California, Los Angeles, California 90024

and

T. A. Tombrello and A. V. Nero
California Institute of Technology, Pasadena, California

(Received 31 May 1972)

The $T=1$ isospin mixing in the 4.57-MeV ($T=0$) state in ^{6}Li is investigated via the $\alpha+d \to {}^6\text{Li}^* \to \alpha+d^*$ reaction and found to be less than 1%.

Considerable controversy continues concerning the isospin-forbidden ^{12}C(d, α)^{10}B*($T=1$) reaction.[1,2] One explanation[3] suggests a two-step reaction process: $\alpha+d \to {}^6\text{Li}^*(T=0,\ 1) \to \alpha+d^*(T=1)$ involving isospin-mixed 2^+ states in ^{6}Li, one predominantly $T=0$ at 4.57 MeV and the other predominantly $T=1$ at 5.36 MeV. The purity of the $T=1$ state has been checked by three different experiments,[4-6] which seem to find a mixing too small to account for the observed effects. The purpose of the present experiment was to look at the isospin impurity in the 4.57-MeV($T=0$) state via exactly the mechanism proposed.[3]

Deuteron breakup by α particles has been studied[7] at several energies. The predominant features are nucleon-α final-state interactions and broad spectator peaks. There is no evidence for a $^1S_0$ n-p final-state interaction, and only a weak indication of $^3S_1$. The excitation function[8] of the reaction ^{4}He(d, p)$n\alpha$ at $\theta_{\text{lab}}=14°$, from $E_d=5.7$ to 14.3 MeV, has not revealed any resonance structure. Extensive d-α elastic scattering data[8,9] exist in this energy region.

We studied the isospin impurity of the $T=0$, 4.57-MeV state in ^{6}Li by measuring the excitation function of the D(α, α')d^* ($^1S_0$) $\to n+p$ reaction from $E_{\text{exc}}=4.3$ to 5.4 MeV, in 100-keV steps, at $\theta_{\text{c.m.}}(d^*)=55$ and 84°. The α-particle beam from the Office of Naval Research–California Institute of Technology tandem accelerator was incident upon a D_2 gas target. α particles and protons from d^* were detected in coincidence in two Si detector telescopes. The angle of the proton telescope was set to be equal to the recoil angle of the d^*. Two-dimensional arrays of the coincident events, detected with a standard electronics setup, were stored in a 4096-channel pulse-height analyzer. The relative n-p energy along the three-body kine-

TABLE I. Cross section for the reaction $d+\alpha \to \alpha+p+n$.

E_{exc} (MeV)	E_0 (MeV)	θ_α (lab) (deg)	θ_p (lab) (deg)	$\theta_{\text{c.m.}}(d^*)$ (deg)	$\langle E_{np}\rangle$ (keV)	$d\sigma/d\Omega$ (μb/sr)	$\sigma(d\alpha \to d^*\alpha)$ / σ elastic ($\times 10^{-6}$)
4.41	8.8	14.3	25	84	20	0.28 ± 0.20	0.2
		8.4	33		310	0.9 ± 0.4	
4.57	9.3	15.4	26.5	84	11	1.9 ± 0.4	1.3
		9.2	35.3		400	2.0 ± 0.3	
4.97	10.5	17.4	29.5	84	50	3.6 ± 0.6	2.8
		10.6	38.8		650	4.7 ± 0.4	

TABLE II. Penetrabilities.

Interaction radius (fm)	$P_{\text{in}(l=2)}$	$P_{\text{fin}(l=2)}$	$\frac{1}{3}\frac{P_{\text{fin}}}{P_{\text{in}}}$
3.5	0.3035	0.01077	0.012
4.0	0.4812	0.02055	0.014
4.5	0.6937	0.03591	0.017

matical loci was $0.007 \leq E_{np} \leq 0.080$ MeV and $(E_{np})_{\text{av}}$ was fairly constant as the bombarding energy E_0 was varied. The relative nucleon-α energies varied with E_0. The D(α, α')d^* cross section increased with E_0. The dependence of the D(α, α')d^* cross section on E_0 mainly reflected the influence of the nucleon-α final-state interactions in the ground states of ^{5}He and ^{5}Li. To study this effect, additional measurements of the reaction D(α, αp)n were performed at $E_0 = 8.8$, 9.3, and 10.5 MeV. In this case the kinematic conditions were chosen to have $E_{np} \sim 0.2$–0.8 MeV, while the nucleon-α relative energies were kept close to those involved in the D(α, α')d^* process. Table I summarizes our data at these three incident energies.

In order to investigate whether there is any appreciable contribution of the n-p final-state interaction in the $^1S_0$ state, the D(α, αp)n data were compared with a simple model which assumed the cross section to be given by the following expression: $[K+R_1(4.57)+R_2(5.36)][A\text{BW}(p\alpha)+B\text{BW}(n\alpha)+C\text{WM}(^3S_1)+D\text{WM}(^1S_0)]$, where A, B, C, D, and K are constants determined by fitting the data. R_1 and R_2 describe the effect of resonances corresponding to the 4.57- and 5.36-MeV states. BW($p\alpha$) and BW($n\alpha$) describe the nucleon-α final-state interaction by Breit-Wigner formulas and use parameters for ^{5}He and ^{5}Li ground states. WM($^3S_1$) and WM($^1S_0$) describe the n-p interaction in the $^3S_1$ and $^1S_0$ states, using Watson-Migdal expressions.

This analysis leads to the following conclusions: (1) χ^2 corresponding to $R_1 = 0$ is twice as large as χ^2 for $K = 0$ and $R_2 = 0$. The best fit is obtained for $K = 0$ with $\chi^2 = 3$. It seems that the reaction D(α, αp)-n proceeds at least partly through the 4.57-MeV resonance.
(2) χ^2 does not change if one assumes $D = 0$, or WM($^1S_0$) = const. In all cases $D \ll A$, B, or C.

Since there is no evidence for any contribution of the reaction D(α, α')d^* ($^1S_0$), we are taking the value of the D(α,α')d^* cross section at $E_{\text{inc}} = 9.3$ MeV as the upper limit of the D(α, α')d^*($T = 1$) cross section. Thus one can crudely estimate the upper limit of the $T = 1$ impurity in the 4.57-MeV state. At the resonance, the ratio $\sigma_{dd^*}/\sigma_{\text{elast}}$ is taken equal to

$$\frac{1}{3}\frac{P_{\text{fin}}}{P_{\text{in}}}\frac{\gamma_{d^*}^2}{\gamma_d^2}.$$

The penetrabilities as functions of the interaction radius are given in Table II.

Taking $\sigma_{dd^*}/\sigma_{\text{elast}} = 10^{-6}$, one obtains $\gamma_{d^*}^2/\gamma_d^2 \leq 10^{-4}$. This indicates that the $T = 1$ impurity in the wave function is $\lesssim 10^{-2}$, which is what one would guess as an upper limit for Coulomb mixing. Therefore, it appears that the reaction mechanism $d + \alpha \to {}^6\text{Li}^*$ ($T = 0$, 1) $\to d^*$ ($T = 1$) $+ \alpha$ cannot play an important role in explaining (d, α) isospin-forbidden processes.

† Supported in part by U. S. Atomic Energy Commission and National Science Foundation grants.

*Present address: D.Ph. N/ME Centre d'Etudes Nucléaires de Saclay, France.

‡ On leave of absence from Institute "R. Bcskovic," Zagreb, Yugoslavia.

[1]H. T. Richards and H. V. Smith, Jr., Phys. Rev. Letters 27, 1735 (1971).

[2]D. Von Ehrenstein, L. Meyer-Schützmeister, J. E. Monahan, A. Richter, and J. C. Stoltzfus, Phys. Rev. Letters 27, 107 (1971), and references cited therein.

[3]J. V. Noble, Phys. Rev. Letters 22, 473 (1969).

[4]P. T. Debevec, G. T. Garvey, and B. E. Hingerty, Phys. Letters 34B, 497 (1971).

[5]M. Baker et al., University of Washington, Annual Report, 1971 (unpublished), p. 80.

[6]C. L. Cocke and J. C. Adluff, Nucl. Phys. A172, 417 (1971).

[7]K. P. Artemov and N. A. Vlasov, Zh. Eksperim. i Teor. Fiz 39, 1612 (1960) [transl.: Soviet Phys.-JETP 12, 1124 (1961)]; G. G. Ohlsen and P. G. Young, Phys. Rev. 136, B1932 (1964); K. Nagatani, T. A. Tombrello, and D. A. Bromley, Phys. Rev. 140, B824 (1965); R. E. Warner and R. W. Bercaw, Nucl. Phys. A109, 205 (1968); T. Tanabe, J. Phys. Soc. Japan 25, 21 (1968); C. W. Lewis, D. P. Saylor, and L. C. Northcliffe, to be published; K. Fukunaga, H. Nakamura, T. Tanabe, K. Hosono, and S. Matuski, J. Phys. Soc. Japan 22, 28 (1967).

[8]R. E. Roth, Ph.D. thesis, University of Wisconsin, 1964 (unpublished).

[9]L. S. Senhouse, Jr., and T. A. Tombrello, Nucl. Phys. 57, 624 (1964).