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

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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 $^{12}\text{C}(d,\alpha)^{10}\text{B}^*(T=1)$ 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 $^4\text{He}(d,p)n\alpha$ 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 $\text{D}(\alpha,\alpha')d^*\,(^1S_0) \to n+p$ 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 ($\times10^{-6}$)
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.

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