Communications

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Anomalous population of two 4^+ states in $^{12}C(^6Li, d)^{16}O$†

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In the reaction $^{12}C(^6Li, d)^{16}O$, two 4^+ states (at $E_x = 10.35$ and 11.096 MeV) are populated with relative strengths of $\sigma(11.096)/\sigma(10.35) \approx 0.5$ even though their reduced α-particle widths to the g.s. of ^{12}C are in the ratio $S_\alpha(11.096)/S_\alpha(10.35) < 10^{-2}$. A two-step process proceeding through the first excited state of ^{12}C offers a likely mechanism of the enhanced feeding of the 11.096-MeV state.

[NUCLEAR REACTIONS $^{12}C(^6Li, d)$, $E = 32$ MeV; measured $\sigma(\theta)$.]

Experimental and theoretical interest in $(^6Li, d)$, or for that matter, $(^7Li, t)$, $(^{12}C, ^8Be)$, and $(^{16}O, ^{12}C)$ derives from the hope that these reactions measure reduced α-particle widths (α-particle spectroscopic factors).[1] Recent work on $^{16}O(^6Li, d)^{20}Ne$ has demonstrated that reduced α-particle widths can be extracted from the cross section in a reasonable distorted-wave Born-approximation (DWBA) framework.[2] The principal idea in this method is that the (unknown) normalization of the DWBA can be obtained from states whose α-particle reduced widths are known, namely, the unbound states. Hence, apart from angular momentum and energy dependence (which DWBA is to describe), the cross section is proportional to the reduced α-particle width. We have noticed an in-

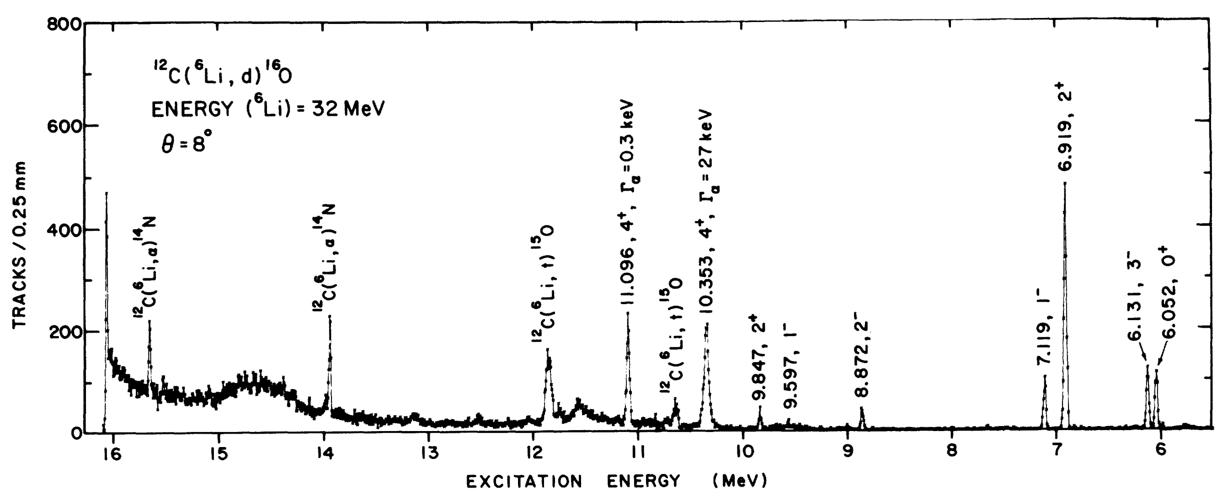

FIG. 1. Spectrum obtained at $\theta = 8°$ for the reaction $^{12}C(^6Li, d)^{16}O$. Peaks arising from particles other than deuterons are labeled by the reaction.

stance in which this proportionality is grossly violated. "α-particle" stripping reactions on ^{12}C strongly populate the 11.096-MeV 4^+ state which has virtually no α-particle width ($\Gamma_\alpha = 0.3$ keV, $S_\alpha \approx 10^{-3}$).[3]

We obtained $^{12}C(^6Li, d)^{16}O$ data with a 32-MeV ^6Li beam from the Argonne tandem using emulsions in the focal plane of an Enge split-pole spectrograph. These emulsions were machine scanned with the automatic nuclear emulsion scanner developed by Dr. J. R. Erskine. Exposures were made at 3° intervals from 8 to 32° and at 140, 145, and 150° to estimate the asymmetry about 90°. The relative normalization of these data was determined with a fixed detector monitoring elastically scattered particles. The nominal target thickness of 30 μg/cm^2 was used to obtain the absolute differential cross section. Our most forward-angle spectrum appears in Fig. 1.

Evidence for direct α particle transfer is found in the weak population of the 2^- state at 8.87 MeV, and strong population of the 0^+ (6.052-MeV), 2^+ (6.92-MeV), and 4^+ (10.35-MeV) members of the four-particle four-hole rotational band, and forward peaking of the angular distributions. However, one of the strongest states in the spectrum is the 4^+ 11.096-MeV state. This state is about half as strong as the 4^+ state at 10.35 MeV, which has $\Gamma_\alpha = 27$ keV.[4] Angular distributions for the two states are given in Fig. 2. The α-particle widths of these states differ by a factor of 100, but the cross sections to these states differ by only a factor of 2. Since these states differ in energy by only 0.65 MeV, but are unbound by 3.5 MeV, neither the energy dependence of the penetrability nor the energy dependence of the DWBA cross section can account for this discrepancy. In fact, since the 11.096-MeV state lies above the 10.35-MeV state, the ratio of *reduced* widths is less than 10^{-2}, and the direct one-step population of the 11.096-MeV state should be less than one percent of that for the 10.353-MeV state.

The possibility of improper identification of the 11.096-MeV state was examined, since a 3^+ state is known to exist at 11.080 MeV. No evidence for a doublet was found in the observed line width, which was always consistent with the experimental resolution (30 keV). Similarly, the extracted excitation energy relative to the low-lying states was consistent only with the excitation energy of

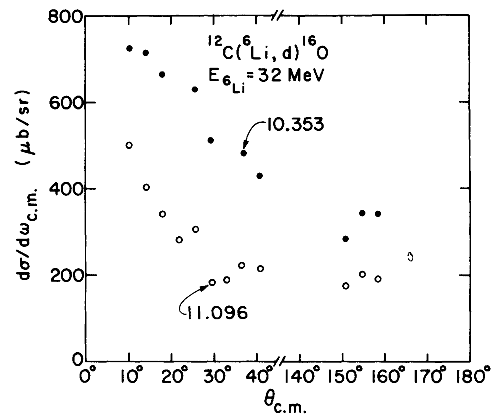

FIG. 2. Angular distributions for the 4^+ states at 10.353 MeV ($\Gamma_\alpha = 27$ keV) and 11.096 MeV ($\Gamma_\alpha = 0.3$ keV).

the 4^+ state. Although there was no reason to suspect the spin-parity assignment or the width of the 11.096-MeV state, we repeated the experiment of Larson and Tombrello $^{12}C(\alpha, \alpha)^{12}C$, the only experiment in which these quantities have been determined. In addition to their angles of detection, our observation of the resonance at $\theta = 158.8°$ [$P_6(\cos\theta) = 0$] definitely eliminated a 6^+ assignment.

A search of the literature revealed that other experiments of α transfer onto ^{12}C have produced this peculiarity (relatively strong population of the 11.096-MeV state), although it was not noted; for example, $^{12}C(^6Li, d)^{16}O$ at $E_{^6Li} = 20$ MeV,[5] $^{12}C(^7Li, t)^{16}O$ at $E_{^7Li} = 15$, 21.1, and 24 MeV,[6] and $^{12}C(^{12}C, ^8Be)^{16}O$ at $E_{^{12}C} = 62.6$ MeV.[7]

The observed anomaly is probably due to a two-step process in which the ^{12}C target is first excited to the 2^+ state at 4.43 MeV, and then α transfer takes place. The second 4^+ state in ^{16}O is an extremely good candidate for being formed by such a process. In a weak coupling picture of the 4p-4h states in ^{16}O, the lowest 4^+ state is the product $^{20}Ne(4^+) \otimes {}^{12}C(0^+)$. A second 4p-4h 4^+ state can be constructed from $^{20}Ne(2^+) \otimes {}^{12}C(2^+)$.[8,9] The 10.35-MeV state has long been identified as the state $^{20}Ne(4^+) \otimes {}^{12}C(0^+)$. The 4^+ state at 11.096 MeV is a likely candidate for the 4^+ state of configuration $^{20}Ne(2^+) \otimes {}^{12}C(2^+)$. Since such a state has as parent the ^{12}C target in its 2^+ state, it should be strongly excited in such a two-step process.

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[1]K. Bethge, Annu. Rev. Nucl. Sci. 20, 255 (1970).
[2]H. T. Fortune, Argonne National Laboratory Physics

Division Informal Report No. PHY-1973B, 1973 (unpublished), pp. 287–323.
[3]J. D. Larson and T. A. Tombrello, Phys. Rev. 147, 760 (1964).
[4]F. Ajzenberg-Selove, Nucl. Phys. A166, 1 (1971).
[5]K. Meier-Ewert, K. Bethge, and K. O. Pfeiffer, Nucl. Phys. A110, 142 (1968).
[6]F. Pühlhofer, H. G. Ritter, R. Bock, G. Brommunat, H. Schmidt, and K. Bethge, Nucl. Phys. A147, 258 (1970).
[7]G. J. Wozniak, H. L. Harvey, K. H. Wilcox, and J. Cerny, Phys. Rev. Lett. 28, 1278 (1972).
[8]A. Arima, H. Horiuchi, and T. Sebe, Phys. Lett. 24B, 129 (1967).
[9]The notation $^{20}Ne(4^+) \otimes {}^{12}C(0^+)$ denotes the weak coupling state formed by coupling four (*sd*) shell particles (the 4^+ state of ^{20}Ne) to the ground state of ^{12}C.