High-lying low-spin cluster states in ^{15}N†

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States in ^{15}N have been studied by comparing the $^{12}C(^7Li,\alpha)^{15}N$ and $^{13}C(^6Li,\alpha)^{15}N$ reactions. States assumed to have an $(sd)^3$ configuration because they are observed strongly in three particle transfer but not in two particle transfer are at 10.70, 12.57, 13.20, and 15.43 MeV, with the 12.57 and 13.20 having the lowest spins. The state previously assigned as $(p_{1/2}\otimes d^2_{5/2})_{11/2^-}$ is found at 13.02 MeV in ^{15}N, in agreement with the previous result of 13.03 MeV.

[NUCLEAR REACTIONS $^{13}C(^6Li, \alpha)$ spectra, E=32 MeV. $^{12}C(^7Li, \alpha)$ spectra, E =34.9 MeV; inferred structure of ^{15}N states by comparison of reactions.]

Strongly excited high-lying states in ^{15}N and ^{15}O have been observed by three particle transfer reactions.[1-4] These states have been assigned high spins[1,2] since they have been produced by reactions having large angular momentum mismatches and are assumed to be composed of simple three particle cluster structures of the form $^{12}C+(d)^3$ and $^{12}C+p(d)^2$. The information on these states has been obtained by comparing the relative populations of these states in ^{15}N and ^{15}O with different reactions.[2,4] Attempts to determine more details about the nature of these states with distorted wave Born approximation (DWBA) calculations[4] have not been successful because only minor differences occur in the shapes of the angular distributions for high L transfers.

In comparing different reactions it is often difficult to be certain that the same states are populated because of the different energy calibrations. For example, in the $^{13}C(\alpha,d)^{15}N$ reaction[5] the state assigned as $[p_{1/2}(d_{5/2})^2{}_{5^+}]_{11/2^-}$ is at 13.03 MeV while in $^{12}C(^7Li,\alpha)$[3] the strongest state is at 13.17 MeV with another state about one third as strong at 13.00 MeV. Since the $(^7Li,\alpha)$ and (α,d) reactions have quite different angular momentum mismatches it is impossible to choose which state observed in $^{12}C(^7Li,\alpha)^{15}N$ actually corresponds to the proposed $p(d)^2$ state and more importantly to determine whether one or two cluster type states exist at about 13.1 MeV in ^{15}N.

In the present work, the structure of ^{15}N is studied by comparing the $^{12}C(^7Li,\alpha)^{15}N$ and $^{13}C(^6Li,\alpha)^{15}N$ reactions. The Li beams were produced with an inverted sputter source[6] and accelerated with the Florida State University super FN tandem Van de Graaff. The sputter type ion source[7] allows easy switching between projectiles making it possible to populate the same final nucleus with two and three particle transfer reactions while having the same ejectile. The ^7Li bombarding energy was 34.9 MeV and the ^6Li energy was 32.0 MeV. These two energies were chosen so that the outgoing α particles populating the 5.30 MeV state in ^{15}N have the same energy for both reactions. Two standard $\Delta E\times E$ Si surface barrier counter telescopes with a computer system were used to provide particle identification. Typical spectra for the two reactions at $\theta_{lab}=15°$ are shown in Fig. 1. The energy resolution was about 100 keV. In order for the two reactions to be compared, the data for $^{12}C(^7Li,\alpha)$ were obtained and then immediately afterwards the $^{13}C(^6Li,\alpha)$ data, so that the electronic gains would be the same for the two cases. Because of slight kinematic differences, the calibration of the observed peaks in the spectra was determined from the 5.30, 8.58, and 9.15 MeV states independently for the two reactions. The centroids of the peaks were determined by fitting them assuming a Gaussian shape for the peaks. The energy calibrations obtained from the two reactions were combined in determining the α-particle energies for other peaks observed in the two spectra. For the prominent peaks, the uncertainty in the energies is ±20 keV and arises from the uncertainty in determining the peak centroids. Data were taken for the $^{13}C(^6Li,\alpha)$ reaction in the laboratory angular range from 12.5°–35° in 2.5° steps. $^{12}C(^6Li,\alpha)^{14}N$ data were also taken at the same angles so that the contaminant peaks could be subtracted from the $^{13}C(^6Li,\alpha)^{15}N$ spectra. The $^{12}C(^7Li,\alpha)^{15}N$ reaction was measured at only four angles since a detailed study of this reaction has been reported earlier by Tserruya, Rosner, and Bethge.[3] To make comparisons between the two reactions simpler, the $^{12}C(^7Li,\alpha)^{15}N$ spectrum has been adjusted for the kinematic differences between this reaction and the $(^6Li,\alpha)$ reaction and the two reactions are plotted together in Fig. 2 so that the α group populating a given state in ^{15}N occurs in the same channel for the two reactions. The angular distributions for the two reactions show the magnitudes of the cross sections for the states being compared to vary by no more than 50% so that the conclusions reached in this work are independent of angle over the angular range measured. Also, both reactions are assumed to be direct at the energies in this work, based on previously published excitation functions measured for $^{12}C(^7Li, \alpha)^{15}N$[3] and $^{12}C(^6Li, \alpha)^{14}N$.[8]

A systematic study of the (α, d) reaction in the $1p$ shell[5] has shown the strongest state in the different spectra to arise from the population of states with the configuration $(d_{5/2})^2{}_{5^+}$. Since ^{13}C can be represented as a $p_{1/2}$ neutron coupled to ^{12}C in the simplest model, the strongest state observed in $^{13}C(\alpha, d)^{15}N$ has been assigned[5] as $[p_{1/2}(d_{5/2})^2{}_{5^+}]_{11/2^-}$ with an energy of 13.03 MeV. As seen in Fig. 1 and Ref. 3, the $^{12}C(^7Li, \alpha)$ reaction populates a doublet of states at 13 MeV and by comparing the $^{13}C(^6Li, \alpha)$ and $^{12}C(^7Li, \alpha)$ reactions the three particle state at 13.02 MeV can be assigned as $p(d)^2$. The 13.20 MeV state is then a three particle state of low spin whose configuration is $(sd)^3$ since no peak is observed in the $(^6Li, \alpha)$ spectrum. The assumption of a low spin

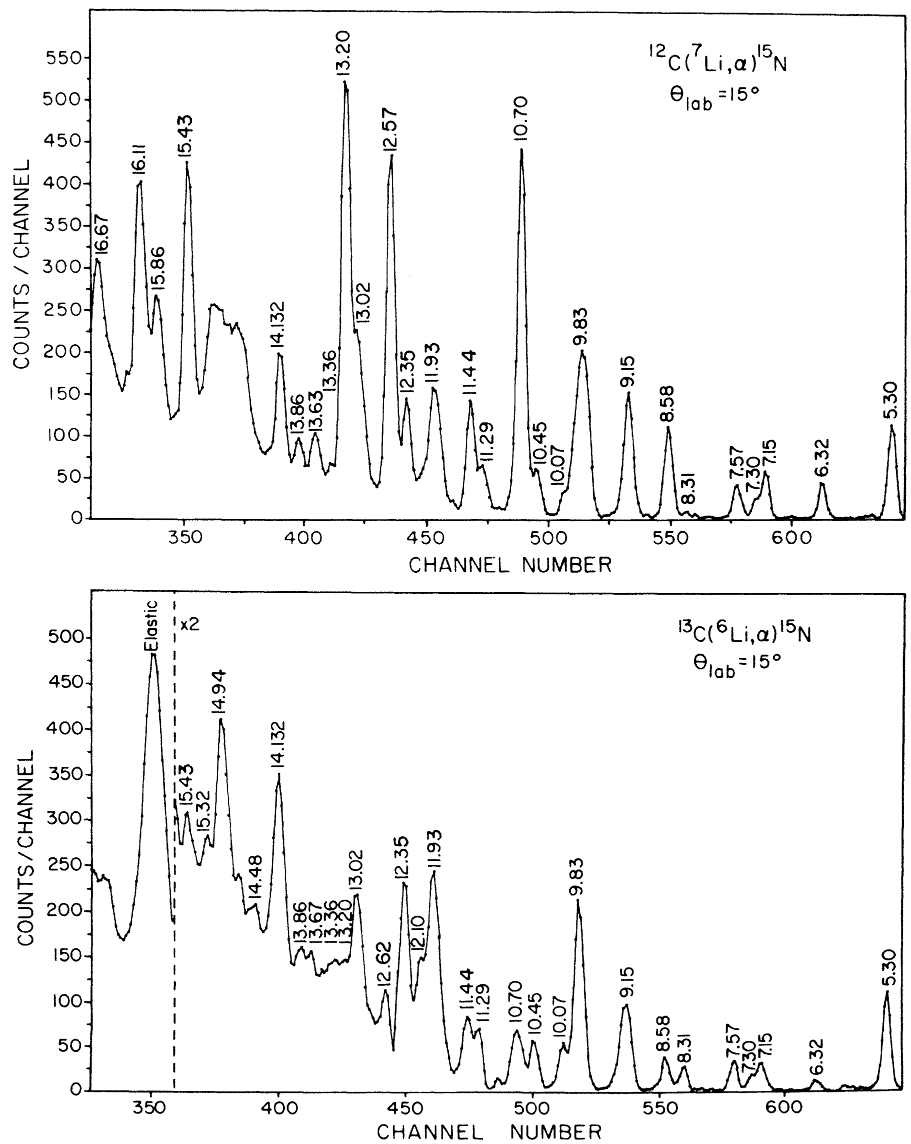

FIG. 1. Spectra for the $^{12}C(^7Li, \alpha)^{15}N$ and $^{13}C(^6Li, \alpha)^{15}N$ reactions for $E(^{7,6}Li) = 34.9$ and 32 MeV, respectively. The two bombarding energies were chosen so that the α particles populating the 5.30 MeV state from the two reactions had the same energy.

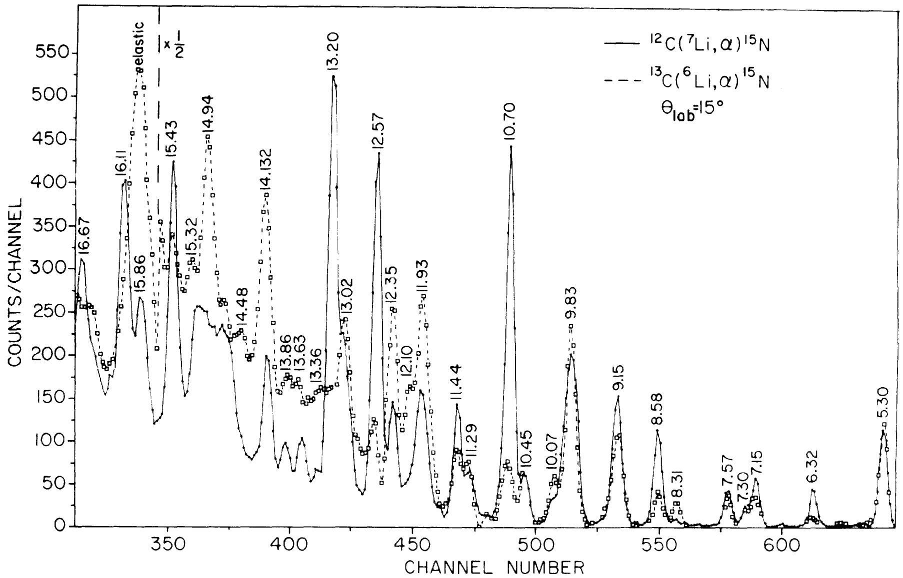

FIG. 2. Spectra for the two and three particle transfer reactions plotted together with the ^{12}C(^{7}Li, α) spectrum adjusted so that groups populating states in ^{15}N occur in the same channel as for the ^{13}C(^{6}Li, α) reaction.

for this state is made because the angular momentum mismatch for the two reactions measured in this work is about $1\hbar$ and the 13.20 MeV state is strongly excited. In a recent high resolution ^{12}C(α,*p*) study[9] two states were observed at 13.02 and 13.18 MeV with the 13.02 MeV state four times stronger than the 13.18 MeV state. Since the (α,*p*) reaction is highly mismatched the weak excitation of the 13.18 MeV state in this reaction also indicates a low spin for this state. The 10.70 MeV state is strongly excited in the three particle transfer reaction but only weakly excited in the two particle transfer reaction supporting the previous designation[4] of this state as having a $(d)^3$ configuration. The 12.57 MeV state also has a low spin because it is strongly populated in (^{7}Li,α) and weakly populated in (^{6}Li,^{3}He) and ^{12}C(^{10}B,^{7}Be)^{15}N[2,4] and a $(d)^3$ configuration because it is not populated in (^{6}Li,α). A similar conclusion can be made for the 15.43 MeV state and because of the weaker population of this state relative to the 10.70 MeV state its proposed $\frac{13}{2}^+$ spin[1,2] is supported.

In summary, comparison between the ^{13}C(^{6}Li,α) and ^{12}C(^{7}Li,α) reactions confirms the previously proposed configurations of $(d)^3$ for the states in ^{15}N observed at 10.70 and 15.43 MeV and also shows two other states with $(d)^3$ configurations at 12.57 and 13.20 MeV. On the basis of angular momentum mismatch between the reactions ^{12}C(^{7}Li,α) and ^{12}C(^{6}Li,^{3}He),[4] the states at 12.57 and 13.20 MeV have lower spins than the 10.70 and 15.43 MeV states. In addition, the state at 13.02 MeV is shown to be $p(d)^2$ and the lower relative intensity of the 13.02 MeV state in the ^{13}C(^{6}Li,α) reaction relative to the ^{13}C(α,*d*) reaction agrees with the proposed $\frac{11}{2}^-$ assignment for this state.[5]

Calculations based on a simple $t+{}^{12}$C cluster model by Buck, Dover, and Vary[10] have been able to describe the high-spin positive parity three particle states in ^{15}N but predict only one low-spin state between 10 and 15 MeV excitation. However, their calculations show that by adjusting the depth of the folded and spin-orbit potentials it is possible to have both the $\frac{3}{2}^+$ and $\frac{7}{2}^+$ cluster states be between 10 and 15 MeV excitation. Thus, it appears possible to describe the existing data with the simple ^{12}C$+t$ cluster model.

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