Identification of analog pairs in ^{13}C and ^{13}N by means of the ^{10}B(^{6}Li, ^{3}He)^{13}C and ^{10}B(^{6}Li, t)^{13}N reactions*

Charles H. Holbrow
Department of Physics and Astronomy, Colgate University, Hamilton, New York 13346

H. G. Bingham† and R. Middleton,
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104

J. D. Garrett
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104, and Brookhaven National Laboratory,‡ Upton, New York 11973
(Received 27 April 1973; revised manuscript received 3 December 1973)

The ^{10}B(^{6}Li, t)^{13}N and ^{10}B(^{6}Li, ^{3}He)^{13}C reactions were induced with $E_{^{6}\mathrm{Li}}$=18 MeV in order to test the assignment of mirror pairs by direct comparison of the resulting spectra. The technique appears to be reliable up to excitations of ~10 MeV for these cases. Some new analog pairs are suggested, and a hitherto unreported state is identified at 9.00 MeV in ^{13}N.

[NUCLEAR REACTIONS ^{10}B(^{6}Li,t), ^{10}B(^{6}Li, ^{3}He) E=18 MeV; measured energy levels, $\sigma(\theta)$; identified J, π and analog pairs of states in ^{13}N and ^{13}C.]

I. INTRODUCTION

The (^{6}Li, t) and (^{6}Li, ^{3}He) reactions on a self-conjugate target are mirrors of each other under the symmetry operation of charge exchange. To the extent that nuclear forces are charge-independent it is reasonable to expect the spectra from such mirror reactions to be quite similar. If the peaks within each spectrum are excited with sufficient variation in intensity, it may be possible to identify analog states by direct comparison of the spectra independently of any assumptions about the reaction mechanism.

Studies of the (^{6}Li, t) and (^{6}Li, ^{3}He) mirror reactions on ^{16}O (Refs. 1, 2), ^{14}N (Ref. 3), and ^{12}C (Ref. 4) indicate that these reactions do in fact provide a convenient way to identify analog states in the residual mirror nuclei. An analysis of the angular distributions of the strong transitions on ^{16}O targets using zero-range distorted-wave Born-approximation (DWBA) calculations in which the transfer of a three-nucleon cluster is assumed[2] suggests that identifications of mirror states excited by (^{6}Li, t) and (^{6}Li, ^{3}He) reactions also may be supported by model-dependent arguments.

In view of the possible usefulness of this technique for identifying mirror states, we have investigated further its reliability by studying the ^{10}B(^{6}Li, t)^{13}N and ^{10}B(^{6}Li, ^{3}He)^{13}C reactions. Our results suggest some new interesting analog pairs, but they also exhibit some of the limitations of the technique. The most interesting result required the assumption of the existence of an additional and hitherto unknown level at 9.00 MeV in ^{13}N. The proof or disproof of the existence of this new level will be a strong test of the validity of the technique of mirror reactions.

II. EXPERIMENT

To induce the ^{10}B(^{6}Li, ^{3}He)^{13}C and ^{10}B(^{6}Li, t)^{13}N reactions a target foil of ^{10}B ~15 μg/cm^2 thick and 95% isotopically pure was bombarded with 18-MeV ^{6}Li^{+++} ions from the University of Pennsylvania tandem Van de Graaff accelerator. The reaction particles were magnetically analyzed in a multiangle magnetic spectrograph and recorded on nuclear track plates at 12 angles and then manually scanned. The target contained a 5% impurity of ^{11}B.

When targets are bombarded with ^{6}Li, deuterons and α particles are prolifically produced. When scanning nuclear emulsions exposed under these conditions, scanners find it difficult to distinguish triton tracks from the numerous deuteron tracks that are present as background. In addition to taking normal precautions to improve the distinguishability of the tritons (see Ref. 2), spectra from each reaction were recorded at a laboratory angle of 11.25° using silicon surface-barrier particle detectors and $\Delta E \times E$ particle-identification techniques. The spectra thus recorded were

identical with those measured with the magnetic spectrograph at the same angle and confirmed our ability to distinguish triton tracks from those of deuterons.

Figure 1 shows a spectrum of tritons from the ^{10}B(^{6}Li, t)^{13}N reaction. It was recorded electronically. Figure 2 presents a spectrum of ^{3}He ions measured using the magnetic spectrograph.

The 5% isotopic impurity of ^{11}B gives rise to the peaks labeled ^{14}N in Fig. 1 and ^{14}C in Fig. 2. These groups or the positions at which they could occur have all been identified and none of them seriously obscures peaks of interest to us. In addition, a peak in Fig. 1 labeled $^{15}O_0$ may arise from the presence of ^{12}C on the target. However, this position is also where $^{14}N_{12}$ should occur. In Fig. 2 $^{15}N_0$ would occur exactly at the position corresponding to the 8.86-MeV level of ^{13}C. There is a slight indication of some excitation in this region. Also shown in Fig. 2 are several peaks thought to arise from an ^{16}O impurity. These peaks are labeled ^{19}F with a subscript to indicate the number of the excited state. The relative intensities of these peaks agree with the previous studies of the ^{16}O(^{6}Li, ^{3}He) reaction.[1] The kinematics of the reaction ^{16}O(^{6}Li, t)^{19}Ne are such that groups corresponding to ^{19}Ne fall outside the region of the recorded spectrum.

The target was exposed to an integrated charge of 5000 μC of $^{6}Li^{+++}$ when recording the ^{10}B-(^{6}Li, ^{3}He)^{13}C spectra. While the ^{10}B(^{6}Li, t)^{13}N spectra were being taken on the spectrograph the target broke, making uncertain the amount of exposure. However, normalization to data taken

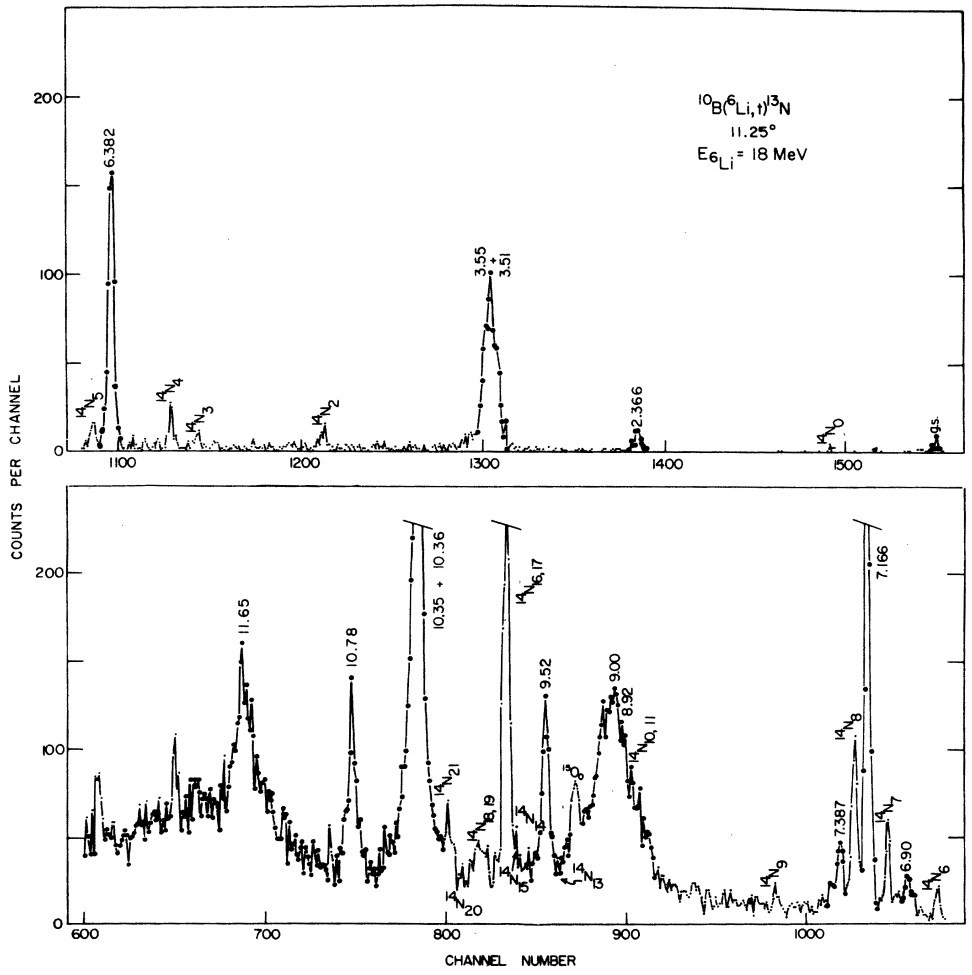

FIG. 1. Spectrum of the ^{10}B(^{6}Li, t)^{13}N reaction taken with a $\Delta E \times E$ particle identification system at a laboratory angle of 11.25° and a bombarding energy of 18 MeV. The peaks are labeled with the excitation energy in MeV of the corresponding states of the residual nucleus. Peaks arising from impurities are labeled with the isotopic symbol of the residual nucleus; the subscript indicates to which excited state the peak corresponds.

electronically indicates the spectrograph exposure corresponded to the collection of 3500 μC of $^{6}Li^{+++}$.

To facilitate direct comparison of these spectra the peaks have been summed and background and impurity groups subtracted, and the results are presented in the bar graph of Fig. 3. One spectrum is shifted to align with the other in order to better exhibit their similarity.

III. DISCUSSION

Within certain portions of the spectra from the $^{10}B(^{6}Li, ^{3}He)^{13}C$ and $^{10}B(^{6}Li, t)^{13}N$ reactions it is easy to identify analog pairs, and because the peaks corresponding to the well-studied[5] low-lying states exhibit the expected similarities, these parts of the spectra are not shown in Figs. 2 or 3.

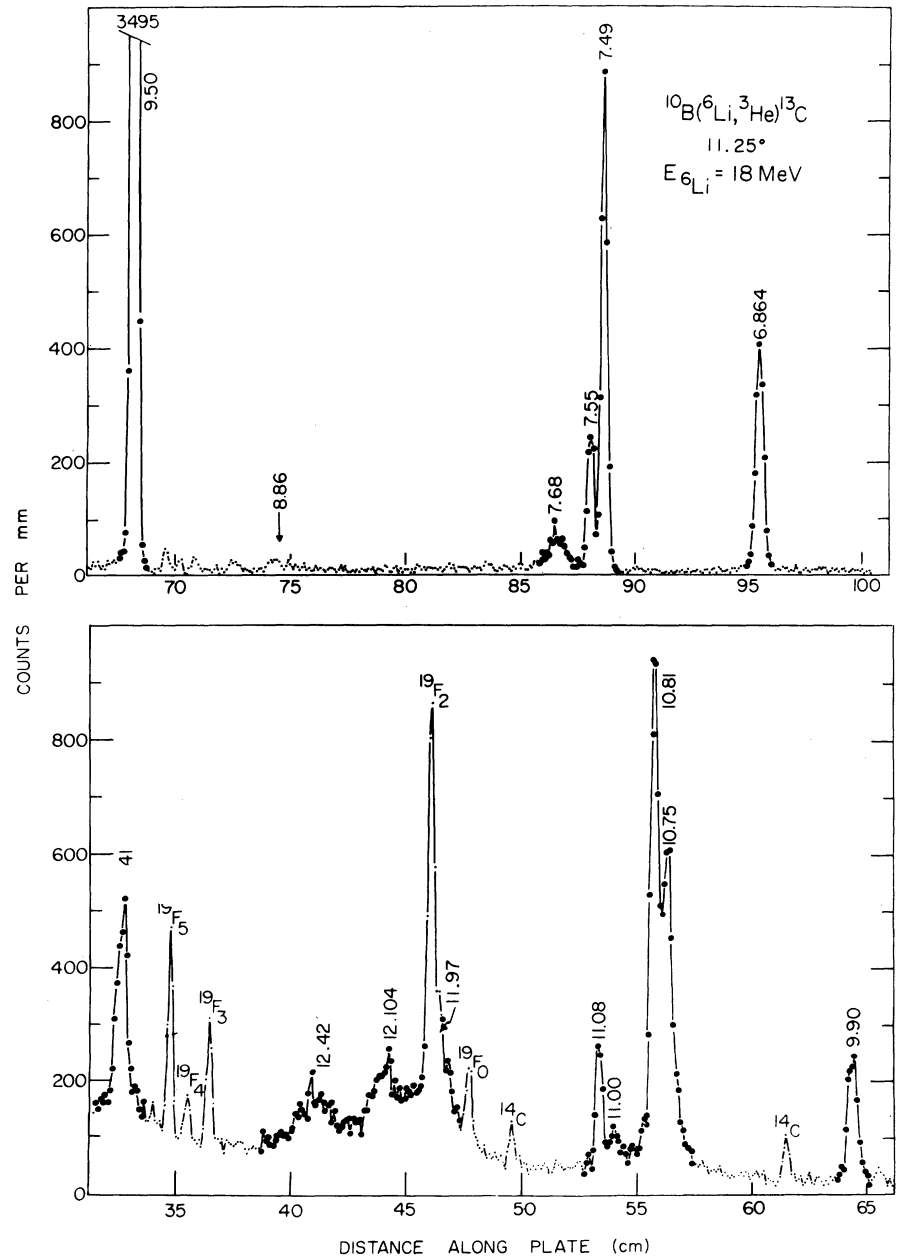

FIG. 2. Spectrum of the $^{10}B(^{6}Li, ^{3}He)^{13}C$ reaction taken with a magnetic spectrograph. The data are recorded at a laboratory angle of 11.25° at a bombarding energy of $E_{^{6}Li}$ = 18 MeV. The notation on the spectrum is as explained in the caption to Fig. 1. The arrow indicates where a peak corresponding to $^{13}C(8.86)$ should occur.

Moreover, from the relative intensities of the peaks shown in Fig. 3, we can immediately identify the 6.86-MeV state of ^{13}C as a mirror state of the 6.38-MeV level in ^{13}N; and we can pair ^{13}C-(7.49) with ^{13}N(7.17), ^{13}C(9.50) with ^{13}N(9.00), ^{13}C(9.90) with ^{13}N(9.52), and ^{13}C(10.81)+ ^{13}C(10.75) with the unresolved doublet at 10.35 + 10.36 MeV in ^{13}N.

Two problems hinder further analysis of the spectra. In some regions several peaks close together have the same size and cannot be distinguished sufficiently for comparison. In regions corresponding to high excitation it is difficult to resolve and identify peaks.

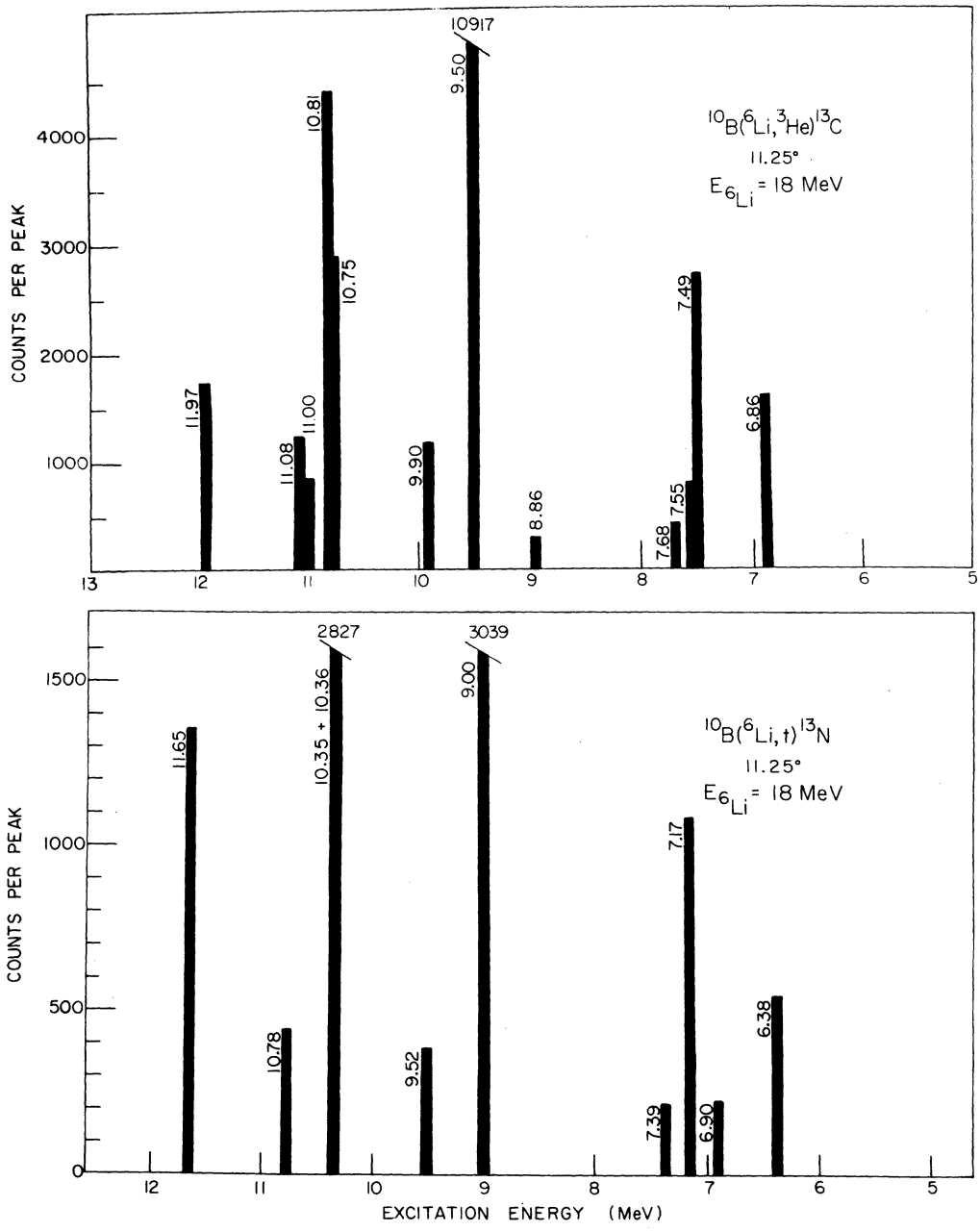

FIG. 3. Bar graphs of the spectra of the ^{10}B(^{6}Li, t)^{13}N and ^{10}B(^{6}Li, ^{3}He)^{13}C reactions taken at 11.25° in the laboratory at a bombarding energy of $E_{^{6}Li}$ = 18 MeV. Each bar represents the sum of the counts in the correspondingly labeled peak in Fig. 1 or Fig. 2 with contributions from impurities and background subtracted out. The horizontal axis represents excitation energy in the appropriate residual nucleus.

The problem of identifying states lying close together and excited with about the same intensity is exemplified by the peaks labeled 7.68, 7.55, 7.39, and 6.90 in Fig. 3. In order to make such identifications we must supplement our results with spins and parities reported in the literature. Then we pair ^{13}C(7.68), $J^\pi = \frac{3}{2}^+$ with ^{13}N(6.90), $J^\pi = \frac{3}{2}^+$ and ^{13}C(7.55), $J^\pi = \frac{5}{2}^-$ with ^{13}N(7.39), $J^\pi = \frac{5}{2}^-$, in agreement with published pairings.[5]

The difficulty in resolving peaks corresponding to high excitation represents an experimental limit on the application of the technique. Figures 1 and 2 show that in the regions corresponding to more than 10 MeV excitation there are broad peaks underlying narrower ones, and there are not the same number of peaks identified in each spectrum as would be required to maintain the one-to-one correspondence of analog states. Moreover, in these regions of the spectra it becomes impossible to be sure that all states arising from impurities have been identified. Consequently, it is unwise to attempt to identify analog pairs in these regions of the spectra.

The outcome of the analysis is the identification of the mirror analog of every state of ^{13}N and ^{13}C appreciably excited in this experiment below ~10.5 MeV excitation. These assignments plus ones established elsewhere[5] are summarized in Fig. 4.

The assignments reveal several interesting features: the identification of ^{13}C(7.49) as the mirror of ^{13}N(7.17); the pairing of ^{13}C(9.50) with a previously unreported state at 9.00 MeV in ^{13}N; and the surprising differences in the widths of the supposed mirror pairs ^{13}C(7.55) - ^{13}N(7.39) and ^{13}C(9.50) - ^{13}N(9.00).

The identification of ^{13}N(7.17) and ^{13}C(7.49) as analogs is unsurprising. They were the last unpaired states in this energy region. However, the result does permit us to assign to ^{13}C(7.49) the $J^\pi = \frac{7}{2}^+$ that characterizes ^{13}N(7.17) (Ref. 5).

More interesting are the identification of a new state at 9.00 MeV in ^{13}N and its pairing with ^{13}C(9.50). Since each of these two states gives rise to the most strongly excited peaks in the corresponding spectra, they are obvious candidates for identification as analog pairs.

To further test this identification we measured angular distributions of the two groups at eight angles. A graph of these data converted to the center-of-mass coordinate system is shown in Fig. 5. Both distributions are forward peaked and similar in shape at the forward angles; they are consistent with our identification of these two

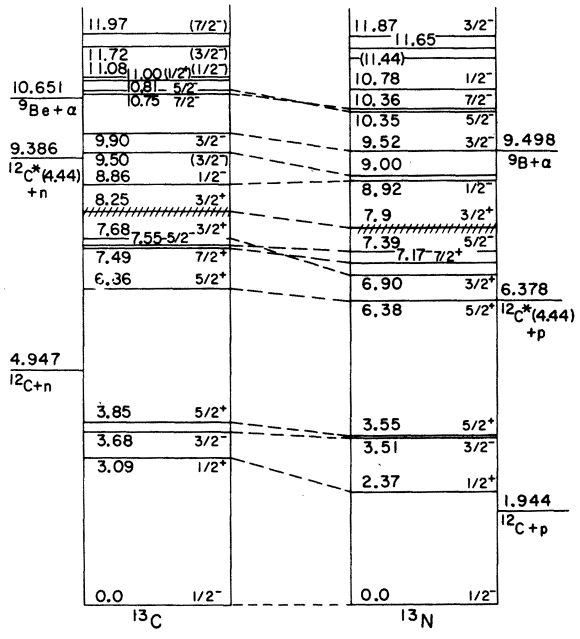

FIG. 4. Energy-level diagram for the levels of the mirror nuclei ^{13}C and ^{13}N below an excitation energy of 12 MeV. Mirror-state assignments, indicated by the connecting dashed lines, are from the literature as summarized in Ref. 5 and the present work except that a possible state at 10.46 MeV that was only observed in an early study of ^{12}C$(n,n'\gamma_{4.4})^{12}$C is not shown. See the text for a discussion of the assignments from the present study. The mirror identification for the known levels is complete up to an excitation of >10 MeV.

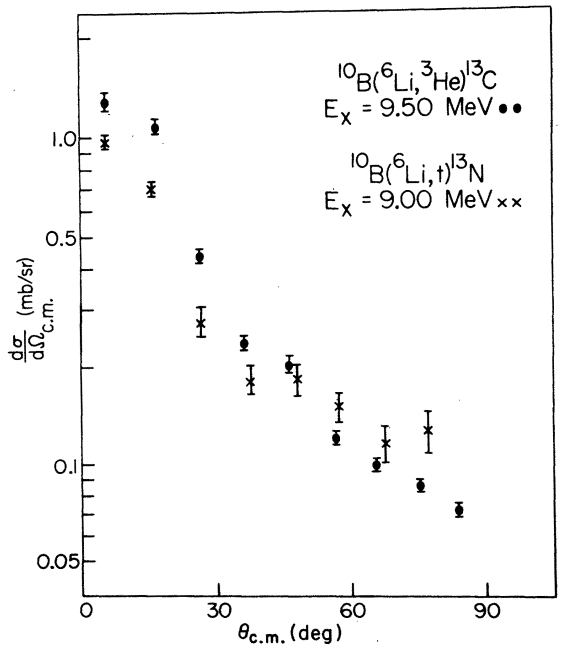

FIG. 5. Angular distributions of the groups corresponding to the 9.50-MeV state of ^{13}C (the solid circles) and to the 9.00-MeV state of ^{13}N (the ×'s) converted to the center-of-mass system.

states as analogs. The dissimilarity at larger angles can be attributed to the difficulty of estimating the background to be subtracted from the peaks corresponding to ^{13}N(9.00). The large error bars represent an estimate of the uncertainty in the subtraction of background. In addition, the contribution of impurity peaks may not be fully accounted for in this region of the angular distribution. A full discussion of the angular distributions of the strongly excited groups and the relative cross sections of the two reactions will be given in a subsequent paper.

There are two aspects of the present data that need explanation if the assignment is to be convincing. It is necessary to be sure that the group in the triton spectrum (Fig. 1) corresponding to ^{13}N(9.00) is distinct from the group corresponding to ^{13}N(8.92) that might be expected in this region. Also we need to explain how one [^{13}C(9.50)] of the analog pair can have a width $\leq$5 keV when the other [^{13}N(9.00)] is 280 keV wide.

The possibility for confusing ^{13}N(9.00) and ^{13}N(8.92) is enhanced by the large natural widths of the two states, 230 keV for ^{13}N(8.92) and 280 keV for ^{13}N(9.00), which assure that the two states overlap. However, it seems likely that ^{13}N(8.92) is not appreciably excited in the ^{10}B(^{6}Li, t)^{13}N reaction because its analog ^{13}C(8.86) is weakly excited as indicated by the arrow in Fig. 2. Because ^{13}N(8.92) is so wide, its intensity would have to be many times greater than that of its analog before it would affect the shape and position of the broad peak that we have identified as ^{13}N-(9.00). There is no evidence at all for the excitation of analog states with intensities sufficiently different to produce such an appreciable effect. Of course it might be that ^{13}C(8.86) and ^{13}N(8.92) are not analogs. However, the previous identification of ^{13}C(8.86) with ^{13}N(8.92) seems firm. Similar resonances are observed in neutron[5,6] and proton[5,7] scattering for these two levels. The β decays of ^{13}O to ^{13}N and ^{13}B to ^{13}C also are in agreement[8] with the identification of ^{13}N(8.92) with ^{13}C(8.86). In order to associate ^{13}C(9.50) with ^{13}N(8.92) as populated by the β^+ decay of ^{13}O, the absence[8] of a ^{13}B β^--decay branch to ^{13}C(9.50) must be explained. Furthermore single-nucleon stripping[9,10] and pickup[11-13] and two-nucleon pickup[13] studies all are consistent with the identification of ^{13}N(8.92) with ^{13}C(8.86). In single-nucleon pickup ^{13}N(8.92) and ^{13}C(8.86) are populated[12,13]; however, ^{13}C(9.50) is not observed.[13] In the ^{12}C(d, p) reaction[9] the angular distribution corresponding to ^{13}C(8.86) exhibits normal stripping shape whereas the angular distribution for the ^{13}C(9.50) level is anomalous and is suggested[9] to be characteristic of a two-step process. Since the ^{13}N(8.92) level populated in single-proton stripping[10] has sizable single-particle strength,[7,12] this level is associated with the ^{13}C(8.86) state which also has appreciable single-particle strength.

Our proposal of two broad states around 8.92 MeV in ^{13}N finds some support in the observation of Fleming *et al.*[13] that in their excitation of states in mass-13 nuclei by two-nucleon transfer, the relative intensities of the states they excited agreed within a factor of 2 with predictions of DWBA except for the state at 8.92 in ^{13}N which was a factor of 600 more intense than predicted. Their resolution was such that they could not distinguish a broad state at 9.00 MeV from one at 8.92 MeV, and the presence of a second state in this region preferentially excited by multinucleon transfer as we propose would explain their result.

Before our identification of ^{13}N(9.00) with ^{13}C-(9.50) can be accepted, it is necessary to understand why the widths of the two states are so different. From the spectra in Figs. 1 and 2 we have measured $\Gamma_{9.00} = 280 \pm 30$ keV and $\Gamma_{9.50} < 30$ keV (See Table I). Other measurements[5] indicate $\Gamma_{9.50} \leq 5$ keV so $\Gamma_{9.00}/\Gamma_{9.5} \geq 56$ rather than ≈ 1 as we might naively expect for mirror nuclei.

A more precise argument eliminates the naivete. Above a few MeV in excitation, states of ^{13}N and ^{13}C are unstable to particle decay, and the partial width for decay by emission of a particle with angular momentum l via a particular channel i can be expressed as

$$\Gamma_i = 2\gamma_i^2 P_l \ ,$$

where P_l and γ_i^2 are, respectively, the penetration factor and the reduced width as defined in Ref. 14. Although in general the total width of a level is the sum of its partial widths, if one channel dominates, it is reasonable to expect the ratio of the widths of two mirror levels such as ^{13}C(9.50) and ^{13}N(9.00) to equal the ratio of the penetration

TABLE I. Widths of some states in ^{13}C and ^{13}N.

State Nucleus E_x (MeV)	This experiment (keV)	Published values of widths [a] (keV)
^{13}C(7.55)	<30	<5
^{13}C(7.68)	60 ± 30	72 ± 10
^{13}C(8.86)	?	161 ± 18
^{13}C(9.50)	<30	≤5
^{13}N(6.90)	120 ± 30	115 ± 5
^{13}N(7.39)	70 ± 30	75 ± 5
^{13}N(8.92)	?	230
^{13}N(9.00)	280 ± 30	...

[a] From Ref. 5.

factors, i.e.,

$$\Gamma_{9.00}/\Gamma_{9.50} \approx P_{9.00,l}/P_{9.50,l}$$

because the reduced width of one state should be closely equal to that of its mirror. Since the penetration factors depend only on simple kinematic and geometric features of the decay, they are easy to determine.[15,16] If we assume the decay of ^{13}N(9.00) and ^{13}C(9.50) is to the ground state of ^{13}C, however, for no reasonable value of l does the ratio of $P_{9.00,l}/P_{9.50,l}$ approach the measured ratio of $\Gamma_{9.00}/\Gamma_{9.50} \geq 56$ (See Table II). On the other hand as Fig. 4 shows ^{13}C(9.50) is unbound to ^{12}C(4.4) by 0.114 MeV while ^{13}N(9.00) is unbound to ^{12}C(4.4) by 2.62 MeV. This marked difference in binding energies results in a large ratio of the penetration factors. Such ratios calculated for different values of l are given in Table II and they show that for $l \geq 1$ the large value of $\Gamma_{9.00}/\Gamma_{9.50}$ is consistent with the assumption that particle decay of these states is largely to ^{12}C(4.4) and not ^{12}C(g.s.).

Such a preferential decay implies that the configurations of ^{13}C(9.50) and ^{13}N(9.00) resemble ^{12}C(4.4) plus a nucleon. Indeed such a configuration for ^{13}C(9.50) has some support[9] because the angular distribution of the ^{12}C(d,p) transition to this state is suggestive of a two-step process. Moreover, studies[5,17,18] of ^{12}C$(n,n'\gamma)^{12}$C show that an appreciable portion of the particle decay of ^{13}C(9.50) is to ^{12}C(4.4). Studies of ^{12}C$(p,p'\gamma)^{12}$C show an appreciable portion of the particle decay of ^{13}N(8.92) is to ^{12}C(4.4) also. If a broad state exists at ^{13}N(9.00), the results of this last experiment may upon reinterpretation support our argument that ^{13}N(9.00) decays with strong preference to ^{12}C(4.4).

The width of ^{13}C(9.50) is remarkably small in view of the availability of an open channel for particle decay to ^{12}C(g.s.). This sharpness may arise from a small reduced width for this channel or it may arise from a high spin such that decay to the ground state of ^{12}C would be inhibited by the angular momentum barrier. This latter situation would favor decay to the 2^+ state at 4.4 MeV in ^{12}C because it could go with an l value lower than needed for decay to the 0^+ ground state. It is also worth noting that earlier studies of Li-induced three-nucleon transfer reactions on ^{12}C, ^{14}N, and ^{16}O targets[1-4] report a definite tendency to populate selected high-angular-momentum states. The tentative $\frac{3}{2}^-$ assignment[5] proposed for ^{13}C(9.50) is not very well established and it is tempting to expect some higher spin assignment for this level that would explain the small width for neutron decay to the ground state of ^{12}C.

TABLE II. Ratio of penetration factors for particle decay of ^{13}N(9.00) and ^{13}C(9.50) to the ground state and 4.439-MeV state of ^{12}C.

l	$P_{9.00}/P_{9.50}$ [a] ^{12}C(g.s.)	^{12}C(4.439)
0	1.1	3.2
1	1.1	19
2	1.2	400
3	1.6	9800
4	2.5	230 000
5	3.8	
6	5.8	

[a] Tabulated values are the ratios as a function of l of particle decay of ^{13}N(9.00) and ^{13}C(9.50) to the ground and 4.439-MeV states of ^{12}C. The calculation is described in Ref. 15.

It is interesting to note that the ratios $\Gamma_{7.68}/\Gamma_{6.90} = 0.63$ and $\Gamma_{7.55}/\Gamma_{7.39} < 0.07$ can be explained by considerations similar to those used to interpret $\Gamma_{9.00}/\Gamma_{9.50}$. The pertinent widths presumably arising chiefly from the particle instability of the respective states are given in Table I. It is important to note that conservation of energy permits ^{13}C(7.68) and ^{13}C(7.55) (see Fig. 4) to be particle unstable only to ^{12}C(g.s.) while ^{13}N(6.90) and ^{13}N(7.39) can decay to ^{12}C(4.4) as well as ^{12}C(g.s.).

Because ^{13}C(7.68) and ^{13}N(6.90) have spin and parity[5] of $\frac{3}{2}^+$ they can decay to the 0^+ ground state of ^{12}C only by emission of nucleon with $l=2$. The ratio of the penetration factors is $P_{7.68,2}/P_{6.90,2} = 0.7$ which is better agreement with the measured ratio of widths, 0.63, than we have a right to expect. The result suggests that most of the decay of ^{13}N(6.90) is to ^{12}C(g.s.) and not to ^{12}C(4.4). This outcome disagrees with other data[7] suggesting that about half of the natural width of ^{13}N(6.90) arises from decay to ^{12}C(4.4).

The calculated ratios of $P_{7.55,l}/P_{7.39,l}$ for decays to ^{12}C(g.s.) are about the same size as $P_{7.68,2}/P_{6.90,2}$ and consequently much different from $\Gamma_{7.55}/\Gamma_{7.39} < 0.07$. The failure of our argument in this case implies that most of the width of $\Gamma_{7.39}$ arises from decay to ^{12}C(4.4) rather than ^{12}C(g.s.). This conclusion is in agreement with the results of Barker *et al.*[19] who attribute 8% of $\Gamma_{7.39}$ to decay to the ground state of ^{12}C and 92% to decay to ^{12}C(4.4).

IV. CONCLUSIONS

The results of this study support previous suggestions[1-3] that the (^{6}Li, ^{3}He) and (^{6}Li, t) reactions on self-conjugate targets are a useful method for identifying analog pairs. These reactions have now been studied for all p-shell self-conjugate

targets[1-4] where both residual nuclei are particle stable in their ground state. This method complements other mirror-state studies since states based on "unusual" configuration[3] and having high angular momentum[1,3] are often populated by the three-nucleon transfer. All analog pairs in ^{13}C-^{13}N have now been identified up to ~10.5 MeV in excitation.

By this technique the 7.17-MeV state in ^{13}N has been identified as the mirror analog of the 7.49-MeV level in ^{13}C. As a consequence the known $\frac{7}{2}^+$ of ^{13}N(7.17) has been assigned to ^{13}C(7.49).

The strong intensity with which the 9.00-MeV state in ^{13}N and the 9.50-MeV state in ^{13}C are excited in the (^{6}Li, t) and (^{6}Li, ^{3}He) reactions and the similarity of the angular distributions strongly suggest they are mirror analogs. Such an identification assumes a new state at 9.00 MeV in ^{13}N distinct from the nearby state ^{13}N(8.92). Such an assumption seems well supported by both direct and indirect arguments. Consequently, we suggest that there are two states near this excitation energy, one of which is the known analog of ^{13}C(8.86) and the other of which is new and the analog of ^{13}C(9.50). It appears to resemble a nucleon coupled to the 2^+ state at 4.44 MeV in ^{12}C.

There is, of course, the possibility that this method may not work. The mirror reactions (^{6}Li, t) and (^{6}Li, ^{3}He) may not excite their respective residual nuclei in the same way and the 9.00 and 9.50-MeV states might then not be mirror analogs. Since the reaction involves the transfer of several nucleons, we could explain away the large intensity with which these levels are excite by invoking "interference" in order to attribute the observed large effects to small components c the wave functions. Such arguments are intrinsically unsatisfying; and, moreover, no discrepancies of this size were observed in studies of (^{6}Li, t) and (^{6}Li, ^{3}He) reactions on ^{12}C (Ref. 4), ^{14}N (Ref. 3), and ^{16}O (Refs. 1 and 2), so that the evidence favors the existence of the doublet ^{13}N(9.00) and ^{13}N(8.92). In any event tests of its existence will test further the validity of the tech nique of mirror reactions and consequently it wi be very interesting to examine further this regio of excitation in ^{13}N.

ACKNOWLEDGMENTS

We acknowledge discussions with Dr. E. K. Wa burton, Dr. D. H. Wilkinson, and Dr. Stanley Hanna. We also wish to thank Jay Bennett for hi assistance in performing this experiment, and w particularly thank Mrs. Anne Fitts for her carefi scanning of the nuclear plates and her help in reducing the data for analysis.

---

*Work supported by the National Science Foundation.
†Present address: Oak Ridge National Laboratory, Oak Ridge Tennessee 37830.
‡Work supported in part by the U. S. Atomic Energy Commission.

[1]H. G. Bingham, H. T. Fortune, J. D. Garrett, and R. Middleton, Phys. Rev. Lett. 26, 1448 (1971).
[2]J. D. Garrett, H. G. Bingham, H. T. Fortune, and R. Middleton, Phys. Rev. C 5, 682 (1972).
[3]H. G. Bingham, H. T. Fortune, J. D. Garrett, and R. Middleton, Phys. Rev. C 7, 57 (1973).
[4]C. H. Holbrow, H. G. Bingham, and J. D. Garrett, Bull. Am. Phys. Soc. 17, 465 (1972).
[5]F. Ajzenberg-Selove, Nucl. Phys. A152, 1 (1970); and references therein.
[6]D. B. Fossan, R. L. Walter, W. E. Wilson, and H. H. Barschall, Phys. Rev. 123, 209 (1961).
[7]G. G. Shute, D. Robsen, V. R. McKenna, and A. T. Berztiss, Nucl. Phys. 37, 535 (1962).
[8]J. E. Esterl, J. C. Hardy, R. G. Sextro, and J. Cerny, Phys. Lett. 33B, 287 (1970); K. W. Jones, W. R. Harris, M. T. McEllistrem, and D. E. Alburger, Phys. Rev. 186, 978 (1969); and references therein.
[9]K. Hosona, J. Phys. Soc. Jap. 25, 36 (1968).
[10]H. T. Fortune, T. J. Gray, W. Trost, and N. R. Fletcher, Phys. Rev. 179, 1033 (1969).
[11]D. Bachelier, M. Bernes, I. Brissaud, P. Radvanyi a M. Roy, Nucl. Phys. 88, 307 (1966); and R. L. Kozub L. A. Kull, and E. Kashy, *ibid.* A99, 540 (1967).
[12]F. Hinterberger, G. Mairle, U. Schmidt-Rohre, P. Turek, and G. J. Wagner, Nucl. Phys. A106, 161 (1968).
[13]D. G. Fleming, J. Cerny, C. C. Maples, and N. K. Glendenning, Phys. Rev. 166, 1012 (1968).
[14]A. M. Lane and R. G. Thomas, Rev. Mod. Phys. 30, 257 (1958).
[15]See e.g., F. Ajzenberg-Selove, H. G. Bingham, and J. D. Garrett, Nucl. Phys. A202, 152 (1973).
[16]J. B. Marion and F. C. Young, *Nuclear Reaction Ana ysis: Graphs and Tables* (North-Holland, Amsterdar 1968), p. 64 *et seq.*
[17]H. E. Hall and T. W. Bonner, Nucl. Phys. 14, 295 (1
[18]H. S. Adams, J. D. Fox, N. P. Heydenberg, and G. M Temmer, Phys. Rev. 124, 1899 (1961).
[19]F. C. Barker, G. D. Symons, N. W. Tanner, and P. Treacy, Nucl. Phys. 45, 449 (1963).