Possibility of a Stripping Mechanism in Transformations Induced by Lithium Ions*

GEORGE C. MORRISON
The Enrico Fermi Institute for Nuclear Studies, The University of Chicago, Chicago, Illinois
(Received July 25, 1960; revised manuscript received September 26, 1960)

Angular distributions of the reaction $Li^7(Li^6,d)B^{11}$ leading to the ground state and first three excited states of B^{11} and the reaction $Li^6(Li^7,t)B^{10}$ leading to the ground state and first excited state of B^{10} have been studied at an incident energy of 2.1 Mev. The principal features of the observed distributions are their asymmetry about 90° and slow variation of cross section with angle. The results suggest that the reactions proceed at least in part by a stripping mechanism with the capture of the alpha-particle core of the lithium projectile. The importance of this mechanism to the experimental investigation of the cluster model is indicated.

THE importance of the reaction (Li^7,p) as a means of studying residual nuclei with a large neutron excess has been previously shown.[1-3] In this note we wish to focus attention on another aspect of the reactions induced by lithium, namely that in which the projectiles Li^6 and Li^7 might behave as $(\alpha+d)$ and $(\alpha+t)$ configurations, respectively. In particular it was felt that a study of the (Li^6,d) and (Li^7,t) reactions should be of importance since (1) in terms of the cluster model,[4,5] the addition of an alpha particle to the target nucleus should be favored as a process whereby the final nucleus is formed with the minimum rearrangement of nucleons, and (2) the zero spin of the captured alpha substructure should simplify the interpretation of the observed angular distributions.

Angular distributions of the reaction products from the bombardment by Li^6 and Li^7 have been studied at an incident energy of 2.1 Mev by means of the University of Chicago 2-Mev Van de Graaff accelerator. Identification of the outgoing particle is achieved with a proportional counter -CsI(Tl) scintillation counter telescope which gives a measure of the dE/dx and E of the emitted particles, respectively. Relative cross sections are obtained by means of a monitor detector located at a fixed angle to the beam direction.

Figure 1 shows the angular distribution in the center-of-mass system of deuteron groups emitted in the reaction $Li^7(Li^6,d)B^{11}$ leading to the ground state (energy release 7.20 Mev) and the first three excited states of B^{11}. By reversing the role of target and projectile it was possible to obtain a complete angular distribution from 0° to 180°. Both runs were taken at approximately the same energy in the barycentric system and normalization involved only the difference in counting rate in the fixed monitor detector. Figure 2 shows the angular distribution of triton groups emitted in the reaction $Li^6(Li^7,t)B^{10}$ leading to the ground state (energy release 1.99 Mev) and the first excited state of B^{10}. Complete angular distributions from 0° to 180° have again been obtained.

The main feature of the angular distributions is their asymmetry about 90°. It is difficult to reconcile this result with the reaction proceeding entirely through a compound nucleus. If the compound nucleus, C^{13}, were formed, the excitation energy would be approximately 27 Mev for an incident energy of 2.1 Mev, and, even in a light nucleus, at such high excitation energies the statistical model which predicts angular distributions symmetrical about 90° should apply.[6] Previous results have indeed shown that there are no resonances in the total cross sections for lithium on lithium reactions in the energy range 1.5 to 2.0 Mev.[7]

Although no attempt has been made to compare the experimental results with any detailed theoretical

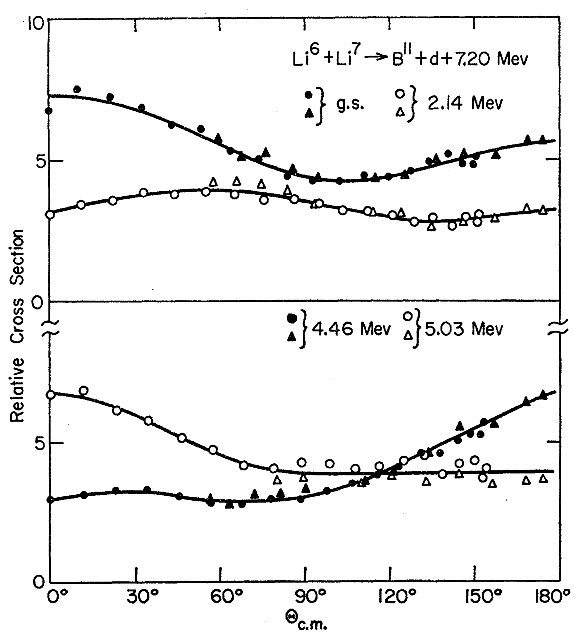

FIG. 1. Angular distributions in the center-of-mass system of deuterons leading to the ground state and the first three excited states of B^{11} as studied in the reactions $Li^7(Li^6,d)B^{11}$ (circles) and $Li^6(Li^7,d)B^{11}$ (triangles).

* This work has been supported in part by the U. S. Atomic Energy Commission.
1 P. G. Murphy, Phys. Rev. **108**, 421 (1957).
2 C. S. Littlejohn, Phys. Rev. **114**, 250 (1959).
3 G. C. Morrison and J. A. Galey, Phys. Rev. **116**, 1583 (1959).
4 K. Wildermuth and Th. Kanellopoulos, CERN Report 59-23, 1959 (unpublished).
5 G. C. Phillips and T. A. Tombrello (to be published).
6 L. Wolfenstein, Phys. Rev. **82**, 690 (1951).
7 E. Norbeck and C. S. Littlejohn, Phys. Rev. **108**, 754 (1957).

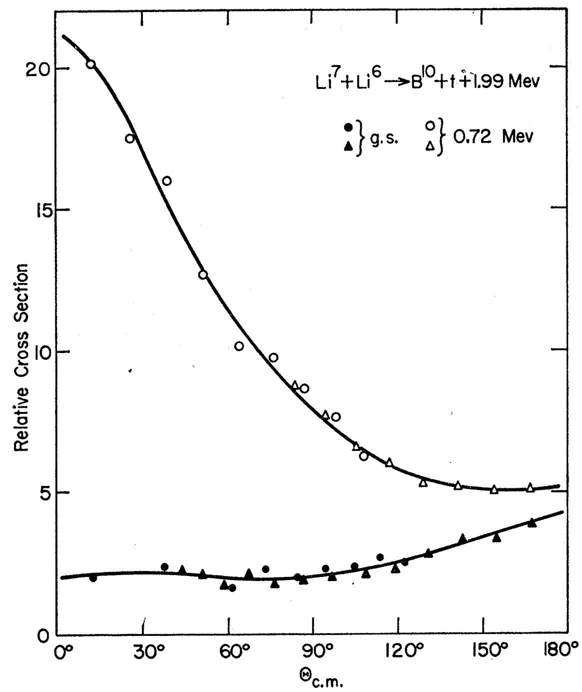

FIG. 2. Angular distributions in the center-of-mass system of tritons leading to the ground state and first excited state of B^{10} as studied in the reactions $Li^6(Li^7,t)B^{10}$ (circles) and $Li^7(Li^6,t)B^{10}$ (triangles).

model at present, the observed asymmetry of the angular distributions suggests that the reactions proceed at least in part by a direct interaction process. Since Li^6 and Li^7 are stable to breakup as an alpha particle and a deuteron or triton by only 1.47 and 2.47 Mev, respectively, it is reasonable to interpret the direct interaction as a stripping process in which the alpha-particle core of the lithium projectile is captured by the target nucleus to leave an outgoing deuteron or triton. Further evidence in support of the reaction mechanism comes from supplementary results obtained on the relative cross sections for emission of various particles. In the reaction Li^6+Li^7 discussed here, the relative cross section for the emission of deuterons or tritons to low-lying levels in B^{11} and B^{10} is enhanced by about a factor of five compared to the emission of protons or alpha particles to low lying levels in B^{12} and Be^9.

A direct comparison of the (Li^6,d) and (Li^7,t) reactions involving the same target and final nucleus is not possible using Li^6 or Li^7 targets since one or other of the reactions involves identical particles which restricts the angular distribution to symmetry about 90°. This feature has been observed in the reactions $Li^7(Li^7,t)B^{11}$ and $Li^6(Li^6,d)B^{10}$. In order to obtain a direct comparison the reactions $Be^9(Li^6,d)C^{13}$ and $Be^9(Li^7,t)C^{13}$ are being currently studied. The results indicate a strong similarity in the angular distributions of the deuterons and tritons leading to the same low-lying levels in C^{13}, which is only understandable on the basis of a direct capture of the alpha particle. Such measurements are being extended and will be published together with a complete report of those obtained in other lithium on lithium reactions at a later time.

If a stripping mechanism is assumed, it is of interest to consider possible values of the angular momentum of the captured alpha particle. In the reaction $Li^7(Li^6,d)B^{11}$, both Li^7 and B^{11} in their ground state and B^{11} in its 5.03-Mev state have spin $\frac{3}{2}-$, so that an alpha particle from Li^6 can be captured with zero angular momentum. In the reaction $Li^6(Li^7,t)B^{10}$, Li^6 in its ground state and B^{10} in its first excited state at 0.72 Mev are both $1+$ levels, so that an alpha particle from Li^7 can again be captured with zero angular momentum. The spins and parities of the remaining levels studied in B^{11} and B^{10} are such that the capture of an alpha particle can only take place with at least $l=2$.

In view of the large Coulomb effects at such low bombarding energies it would be expected that simple stripping formulas of the Bessel function type[8] would not be applicable here. It is surprising, therefore, that forward peaking as would be predicted on this basis is observed in each of the reactions leading to the levels where $l=0$ is allowed. In addition, when one calculates the momentum transfer involved in these reactions, such simple formulas appear successful in correlating the observed maxima and minima of the experimental angular distributions for reasonable values of the interaction radius in the range 4.0×10^{-13} to 5.0×10^{-13} cm. In this connection some results obtained in low-energy deuteron stripping have shown very good agreement with the simple stripping theory.[9] Unfortunately the limitations of the available experimental equipment prevent a study in which the bombarding energy is raised above 2 Mev.

In conclusion, it would appear that if the angular distributions are amenable to a detailed theoretical interpretation which reflects the operation of selection rules on the captured alpha particle, part of the usefulness of lithium beams in stripping experiments is related to the validity of the cluster model, since with them we have a means of adding alpha particles to nuclei in a known way as revealed by the deuteron or triton emitted in the reaction. This should be true not only in respect to the observed angular distributions, but also their observed relative intensities should give information on the parentage of the final state of the residual nucleus when considered as a "core unexcited" plus alpha particle substructure.

ACKNOWLEDGMENTS

The author is grateful for the aid given by M. N. Huberman and M. Kamegai in carrying out this work, and to L. Palmer and J. Erwood for dependable operation of the Van de Graaff accelerator. He is indebted to S. K. Allison and G. R. Satchler for valuable discussions.

[8] S. T. Butler, Phys. Rev. **80**, 1095 (1950).
[9] J. P. F. Sellschop, Phys. Rev. Letters **3**, 346 (1959).