Angular Distribution of Li^8 from $Be^9(Li^7,Li^8)Be^8$*

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Angular distribution curves and an excitation curve are given for Li^8 produced by the reaction $Be^9(Li^7,Li^8)Be^8$ with Li^7 beam energies between 2.0 and 4.0 Mev. The angular distribution may be roughly approximated by $\sin^2\theta$ in the center-of- mass system, with the central peak shifting forward as the energy is increased. The total cross section for the production of Li^8 increases with energy with no indication of resonances.

I. INTRODUCTION

A NUMBER of nuclear reactions of lithium beams with light elements have been reported,[1–4] but very little is known concerning the angular distribution of the reaction products from such reactions. The reaction $Be^9(Li^7,Li^8)Be^8$, $Q=0.37$ Mev is particularly interesting. Because of the loosely bound neutron in Be^9 it might be expected to be of the pure neutron-transfer type, although proton transfer is another logical possibility. The low bombarding energies used (2.0 to 4.0 Mev) and the high Coulomb barrier should make compound nucleus formation negligible. The low Q of the reaction allows only the ground state and first excited state (0.95 Mev) of Li^8 and only the ground state of Be^8 to be formed.

II. APPARATUS AND PROCEDURE

The beam of Li^7 ions used in this work was produced by the Minnesota Van de Graaff machine, which has recently been modified to produce lithium ions from an ion source similar to that developed at Chicago.[4,5] After leaving the accelerator a second electron was stripped from the lithium ions in a differentially pumped, gas-filled stripping cell, and the beam was deflected by a 90° magnet. Immediately following this magnet was a magnetically operated beam shutter which was used to interrupt the ion beam periodically, as described below. The laboratory containing the target and detecting equipment was separated from the accelerator and deflecting magnet by a wall six feet thick, which greatly assisted in reducing the background radiation at the detectors. The ion beam was focused on the target by a system of strong-focusing electrostatic lenses.

The angular distribution target chamber has been described previously,[6] although in this experiment the magnetic analyzer and plate holder were replaced by a copper shield-cone and scintillation counter, as shown in Fig. 1. The lid and proportional counter at the top of the chamber were replaced by a $\frac{1}{4}$-in. thick Lucite window and a second scintillation counter, used to monitor the total production of Li^8.

The target used in the angular distribution work was a Be foil 30 microinches thick, mounted on a rotatable wire frame at the center of the target chamber. A 6-microinch target was employed in some cases in an effort to improve the resolution, but no significant difference was observed.

The copper cone was required to shield the cylindrical plastic scintillator from gamma rays produced by the decay of Li^8 nuclei which remained in or near the target. The outer end of the copper cone was sealed with a 0.002-in. steel foil which served to catch the Li^8 nuclei whose beta decay was to be detected by the scintillator. It was found that a foil of this thickness scattered some of the beta rays coming directly from the target so that they entered the scintillator and produced a small isotropic background count. However, this effect could be measured by temporarily placing another thin foil over the opening in the apex of the cone. This kept the Li^8 nuclei from entering the cone, yet had only a small effect upon the 13-Mev beta rays from the target and vicinity.

The copper cone and attached detector could be rotated about the target so that the emission of Li^8 nuclei could be studied over a range of angles from 5° to 160°. The dimensions of the chamber and cone limited the angular spread of particles entering the cone to ±3°.

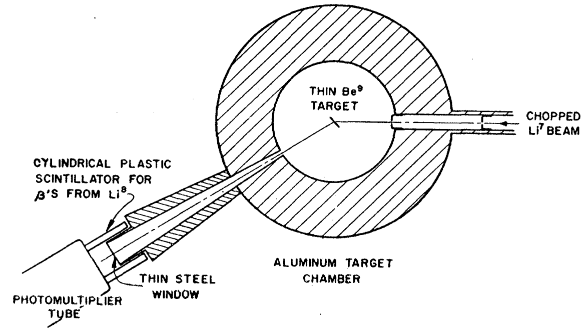

FIG. 1. Apparatus for measuring the angular distribution of short-lived radioactive products.

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[1] E. Norbeck, Jr., and C. S. Littlejohn, Phys. Rev. **108**, 754 (1957).
[2] C. S. Littlejohn, Phys. Rev. **114**, 250 (1959).
[3] P. G. Murphy, Phys. Rev. **108**, 421 (1957).
[4] E. Norbeck, Jr., Phys. Rev. **105**, 204 (1957).
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[6] Holmgren, Blair, Simmons, Stratton, and Stuart, Phys. Rev. **95**, 1544 (1954).

Detection of the Li^8 nuclei in the presence of many other reaction products was made possible by the fact that the lithium nuclei emit 13-Mev beta rays with a half-life of 0.84 seconds.[7] To take advantage of this the target was bombarded for 1.2 seconds, after which the Li^7 ion beam was interrupted by the shutter mentioned above; after a delay of 0.03 second the counters were turned on for approximately 1.2 seconds. The 0.03-second delay allowed sufficient time for shutter operation and also permitted any B^{12} formed to decay by more than one half-life. In addition to $B^{12}(T_{\frac{1}{2}}=0.02$ second, $E_{\max}=13$ Mev),[7] other radioactive products which might be detected are $C^{15}(T_{\frac{1}{2}}=2.4$ seconds, $E_{\max}=10$ Mev)[4,7] and perhaps H^4, if it is bound. The 0.03-second delay was found to be sufficient to reduce the B^{12} activity to a negligible amount. The correction for the small amount of C^{15} found at the most forward angles has been subtracted from the observed data in the curves appearing in this article. No unexplained activities were found that might be attributed to H^4; however, since H^4 has never been seen there is the possibility that it may have the same lifetime as Li^8. This possibility was investigated by placing over the entrance to the copper cone a foil thick enough to stop Li^8 while yet sufficiently thin to have little effect on H^4. No activity was observed that might be attributed to H^4.

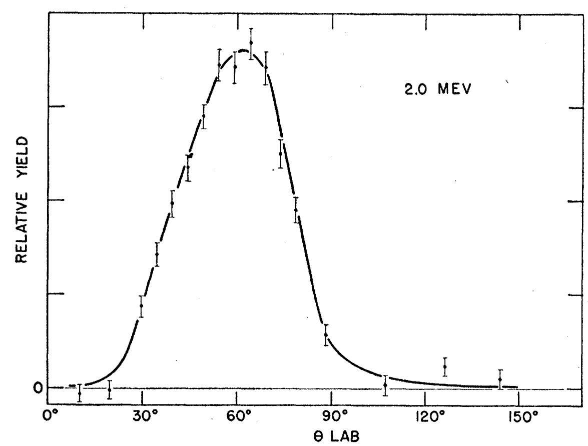

FIG. 2. Laboratory angular distribution of Li^8 from the reaction $Be^9(Li^7,Li^8)Be^8$ with a 2.0-Mev Li^7 beam.

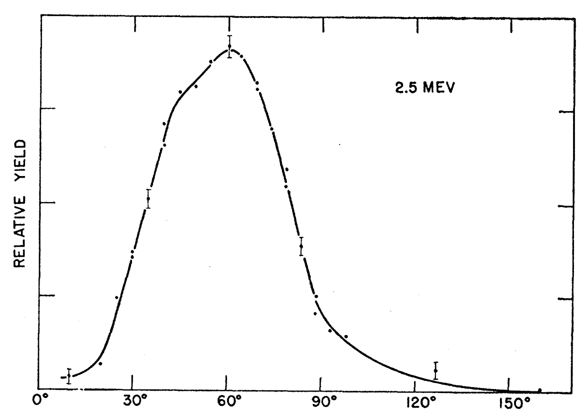

FIG. 3. Laboratory angular distribution of Li^8 from the reaction $Be^9(Li^7,Li^8)Be^8$ with a 2.5-Mev Li^7 beam.

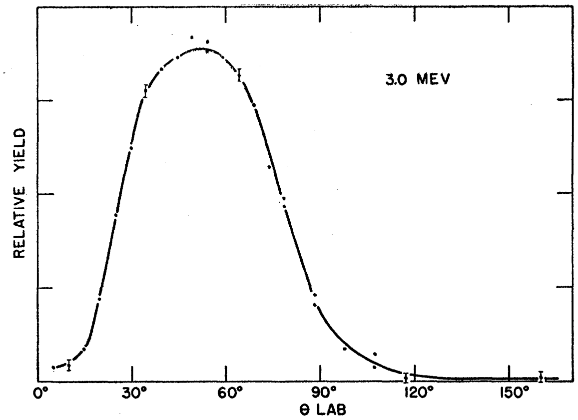

FIG. 4. Laboratory angular distribution of Li^8 from the reaction $Be^9(Li^7,Li^8)Be^8$ with a 3.0-Mev Li^7 beam.

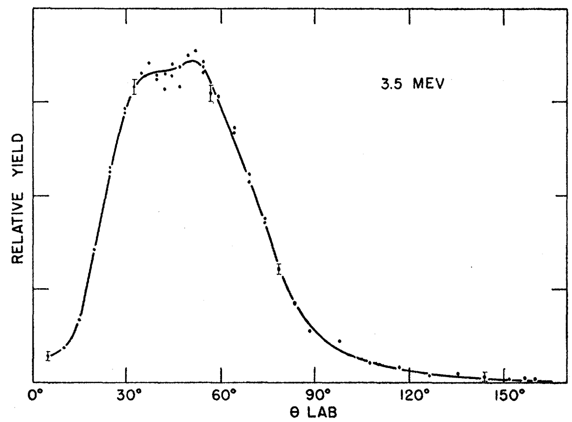

FIG. 5. Laboratory angular distribution of Li^8 from the reaction $Be^9(Li^7,Li^8)Be^8$ with a 3.5-Mev Li^7 beam.

The pulses from the movable scintillation counter, after suitable amplification, were counted with a 20-channel pulse-height analyzer. The monitor counter was normally connected to two scale-of-1000 circuits with pulse-height discriminator biases set to separate the beta-ray pulses from other smaller pulses which were constantly present. The decay time measurements were made using a time-to-height converter similar to that described by Kane.[8]

The target chamber for the excitation curve study was a Faraday cup having its entrance guarded by a magnetic field to insure accurate beam measurement. The efficiency of charge collection was tested by comparing the yield found with a Li^{7++} beam with that found with a Li^{7+++} beam. At the end of the cup was the target. A slab of Be 0.079 in. thick was employed during the determination of the thick target yields,

[7] F. Ajzenberg and T. Lauritzen, Revs. Modern Phys. **27**, 77 (1955).

[8] John V. Kane, Rev. Sci. Instr. **30**, 374 (1959).

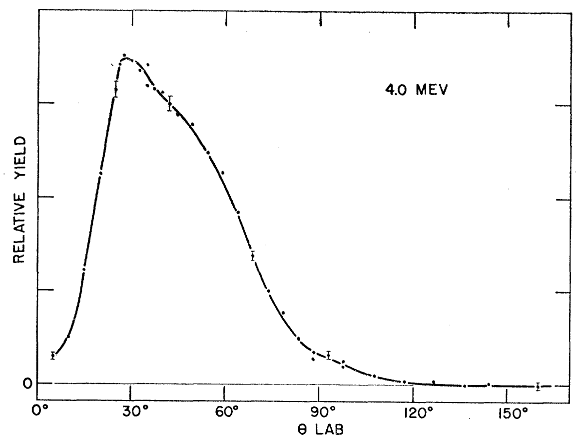

FIG. 6. Laboratory angular distribution of Li^8 from the reaction $Be^9(Li^7,Li^8)Be^8$ with a 4.0-Mev Li^7 beam.

while a thin film of Be evaporated on an aluminum backing was used in determining the thin target yield curve.

Since the largest part of the Li^8 produced goes in the forward direction, nearly all of the Li^8 is stopped in the target. The beta rays resulting from the disintegration of these Li^8 nuclei were detected by a plastic scintillator placed directly in front of the target. Between the target and the scintillator was a plate of 0.12-in. aluminum which absorbed any low-energy beta rays, such as those from He^6 produced in the Li^7-Li^7 reactions.

The energy of the Li^7 ions from the Van de Graaff machine was calibrated by measuring the yield of 17-Mev gamma rays from the Li^7-p reaction. A thick ice target was used so that the resonance appearing at 441.2 kev[9] when Li^7 is bombarded with protons produces, in this case, a step in the gamma-ray yield which is centered at 3.07 Mev.

III. RESULTS

The measured, laboratory angular distributions with the various backgrounds subtracted appear in Figs. 2–6. The shape of the curves suggest unresolved fine structure which might be expected if both the ground state and the 0.95-Mev state of the Li^8 were produced in comparable amounts. A preliminary analysis indicates that these data are not incompatible with the spherical Bessel function type of distribution such as is predicted by a simple direct-reaction theory.[10] The forward shift in the maximum as a function of increasing beam energy is present in the center-of-mass angular distribution as well as in the laboratory distribution. Making use of the stripping-theory concept, it may be argued qualitatively that the reaction is of the neutron-transfer type and not of the proton-transfer type. According to the simple stripping picture, the peak of the angular distribution curve should shift as a function of beam energy in such a way that the momentum transfer, corresponding to the peak angle, remains constant. If the Be^9 becomes Li^8 by giving up a proton, the kinetics of the reaction show that the peak in the angular distribution curve would shift backward with increasing energy. Similarly, if the Li^7 picks up a neutron to become Li^8, the peak would move the other way.

Both thick- and thin-target yields of Li^8 are shown in Fig. 7. While the shape of these curves is quite good,

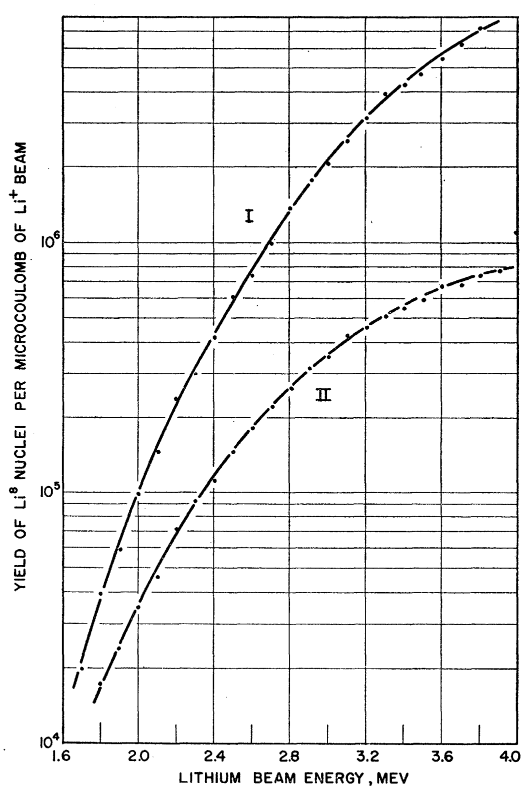

FIG. 7. Yields and cross sections for $Be^9(Li^7, Li^8)Be^8$ estimated from measurements of the beta-counting rate of the Li^8 produced. Curve I—yield of Li^8 nuclei per microcoulomb for a thick Be metal target; Curve II—yield of Li^8 nuclei per microcoulomb for a thin, 6-microinch, Be target.

the absolute values may be in error by as much as 25%. From a comparison of these curves one can calculate that the thin target produced an energy loss of 80 kev for 2-Mev Li^7 ions. With 2.89 Mev cm^2/mg for the stopping power of Li^7 in Be at 2 Mev,[11] this energy loss corresponds to a beryllium layer 6 microinches thick. The cross section in cm^2 may be calculated by multiplying the thin-target yield by 8.65×10^{-32}. These results combined with the measurements made at Chicago[1] cover the energy range from 1.1 Mev to 3.9 Mev.

IV. ACKNOWLEDGMENTS

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[11] S. K. Allison (private communication).