for an isotope of $_9F$ with a spin 5/2, making use of the odd neutron point $N=9$, if such an isotope is discovered.

Unpublished work by Trigg[3] on the theory of allowed favored beta-transitions provides an independent check on the ideas and semi-quantitative relations expressed in Eqs. (1), (2), and (5). Trigg finds that the deviations from L–S coupling estimated from Eq. (5) result in values for the nuclear matrix element $|M|^2$ of the mirror nuclei beta-decay transitions such that $ft|M|^2$ is relatively constant.

Several authors[4–6] have suggested that the nucleons lose a substantial portion of their anomalous magnetic moment in complex nuclei. This effect, if it occurs, should show up most clearly just before and just after the closing of shells where the single particle picture is expected to be most reliable. However, the magnetic moments of C^{13}, N^{15}, O^{17}, F^{19}, K^{41}, Y^{89}, and Pb^{207} are all close to the appropriate Schmidt limits computed for nucleons with the observed free nucleon moments. These examples would seem to place a fairly small upper limit on the size of the suggested effect.

The author wishes to express his sincere appreciation to Professor E. Feenberg for many helpful suggestions and discussions.

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[4] F. Bloch, Phys. Rev. 83, 839 (1951).
[5] H. Miyazawa, Prog. Theor. Phys. 6, 263 (1951).
[6] A. de Shalit, Helv. Phys. Acta 24, 296 (1951).

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The Disintegration of Lithium by Deuteron Bombardment*

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Thin target excitation curves for the $Li^7(d,n)$, $Li^6(d,n)$, and $Li^7(d,p)$ reactions are presented. The neutron data were taken at 90° to the deuteron beam using a BF_3-filled proportional counter in the long geometry. Resonances were observed in the $Li^6(d,n)$ reaction at 0.41 and at 2.12 Mev, in the $Li^7(d,n)$ reaction at 0.68, 0.98, and 2.1 Mev, and in the $Li^7(d,p)$ reaction at 0.75, 1.00, and 1.4 Mev. These resonances correspond to excited states in Be^8 at 22.58 and 23.86 Mev and in Be^9 at 17.22, 17.45, 17.8, and 18.3 Mev. The cross section of the resonances observed in the $Li^6(d,n)$ reactions were 9 and 41 millibarns/steradian, those for the $Li^7(d,n)$ reaction were 39, 43, and 58 millibarns/steradian, and those for the $Li^7(d,p)$ reaction were 0.230, 0.235, and 0.255 barn.

I. INTRODUCTION

The disintegration of lithium by deuterons has been extensively studied. Recently Whaling, Evans, and Bonner[1] observed the neutrons emitted in the $Li^6(d,n)$ reactions. They detected the neutrons emitted in the direction of the deuteron beam by means of the argon recoils in a proportional counter filled with argon at atmospheric pressure and biased to count neutrons greater than 1 Mev. Whaling and Bonner[2] studied the alpha-particles from the reaction $Li^6(d,\alpha)\alpha$ and the protons from the reaction $Li^6(d,p)Li^7$. They obtained excitation functions over the energy range from 190 kev to 1600 kev using a 150 micrograms per cm^2 $Li^6{}_2SO_4$ target enriched to 95 percent Li^6. These excitation curves showed evidence for a level in Be^8 at 22.46 Mev.

The neutrons from the $Li^7(d,n)Be^8$ reaction have been studied by Bennett, Bonner, Richards, and Watt,[3] and by Whaling, Evans, and Bonner.[1] Both of these groups observed the neutrons in the direction of the deuteron beam. The beta-particles from the reaction $Li^7(d,p)Li^8$ were also studied by Bennett, Bonner, Richards, and Watt.[3] Their excitation curve indicated that a resonance might possibly exist at 1.35-Mev deuteron bombarding energy. However, their data did not extend far beyond 1.35 Mev so the evidence was not considered conclusive.

The work to be described in this paper was undertaken with the hope of expanding the knowledge of lithium disintegration by observing the neutrons from a thin target at an angle to the deuteron beam differing from that of previous observations, and by using a neutron counter that was more uniformly sensitive to neutron energies over a wide range.

III EXPERIMENTAL METHODS

The Li^7 target used in these experiments consisted of 51 micrograms per cm^2 of normal Li_2SO_4 evaporated on a silver disk. The Li^6 target was 95 micrograms per cm^2 of Li_2SO_4 enriched to 95 percent Li^6. The Li^6 was kindly loaned to us by the Isotopes Branch of the Oak Ridge National Laboratories. Since Li_2SO_4 is hygroscopic, picking up one water molecule for every Li_2SO_4 molecule, there is a 20 percent uncertainty in the weight of these targets. Since the targets were weighed immediately after evaporation, all the calculations are based on the assumption that the Li_2SO_4 had not picked up any

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[1] Whaling, Evans, and Bonner, Phys. Rev. 75, 688 (1949).
[2] W. Whaling and T. W. Bonner, Phys. Rev. 79, 258 (1950).
[3] Bennett, Bonner, Richards, and Watt, Phys. Rev. 71, 11 (1947).

water. The targets were bombarded on the Rice Institute Van de Graaff accelerator using a magnetic analyzer to determine the energy of the deuteron beam. The targets were held in a multiple position target chamber so that the Li^6 target, the Li^7 target, and a blank silver disk for obtaining the neutron background could alternately be placed in the beam. This enabled all the data for a given deuteron energy to be obtained at approximately the same time. Since the Li^7 target contained 7.3 percent Li^6 and the Li^6 target contained 5 percent Li^7, it was necessary to correct the data for the presence of the other isotope; these corrections were never over 10 percent of the experimental data.

The neutron counter used was a shielded counter of the type described by Hanson and McKibben.[4] The proportional counter was filled to a pressure of 30 cm with BF_3 enriched to 95 percent B^{10}. A counter of this type has an approximately uniform efficiency for neutron energies from 10 kev to 3 Mev. The counter was placed at 90° to the deuteron beam, 7.3 cm from the center of the target. In order to reduce the neutron background, due to the deuteron bombardment of the unavoidable carbon contamination on the various beam defining apertures, cans filled with Borax solution were stacked between the counter and these extraneous sources of neutrons. The beam was moved to a new position on the target whenever an appreciable carbon deposit built up.

For the neutron cross-section measurements the efficiency of the long counter was calibrated using a Po—Be source of known strength at a distance of 1 m. This source was loaned to us by the Los Alamos Scientific Laboratory and had been calibrated by them with an accuracy of about 8 percent. Absolute cross-section measurements were made at 0° and 90° to the deuteron beam with the long counter at a distance of 1 meter.

III. EXPERIMENTAL RESULTS

1. Li^6

Two reactions having neutrons as end products are known to occur when Li^6 is bombarded with deuterons.

$$Li^6+H^2\rightarrow(Be^8)\rightarrow Be^7+n+3.34 \text{ Mev}, \quad (1)$$

$$Li^6+H^2\rightarrow(Be^8)\rightarrow He^4+He^3+n+1.72 \text{ Mev}. \quad (2)$$

In reaction 2, since the compound nucleus breaks up into three particles the neutron may be emitted with any energy from zero up to the maximum. Whaling, Evans, and Bonner[1] used a counter that was biased so as not to count neutrons having energy less than 1 Mev, hence their data did not include a large part of the low energy neutrons[5] coming from reaction 2. Since a long counter has an approximately uniform efficiency for low and high energy neutrons, practically all the neutrons from both reactions are included in the present experiment.

[4] A. O. Hanson and J. L. McKibben, Phys. Rev. **72**, 673 (1947).
[5] J. W. Butler and W. Whaling, Phys. Rev. **78**, 72 (1950).

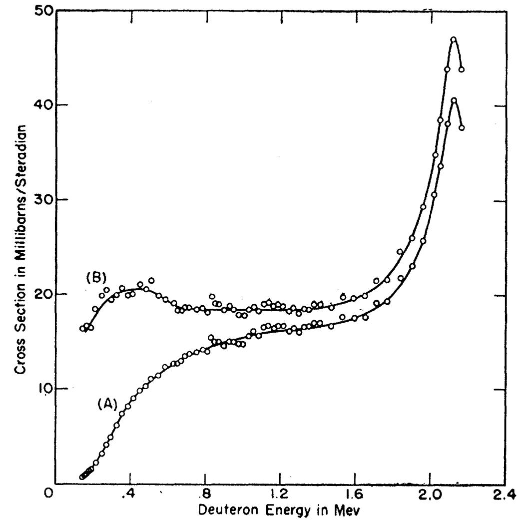

FIG. 1. Cross section for $Li^6(d,n)$ taken at 90±20 degrees to the deuteron beam. Curve A shows the data uncorrected for Coulomb penetrability. Curve B shows the data corrected for Coulomb penetrability and is plotted in arbitrary units. The deuteron energy is that at the center of the target.

Figure 1 shows the neutron cross section as a function of bombardment energy. Curve A is the cross section in millibarns per steradian at 90±20° to the deuteron beam. Curve B is the preceding data corrected for the Coulomb penetrability of the incoming deuteron. This correction was made by dividing the product σE by the function Γ. The Γ function was taken from the data of Christy and Latter.[6] Their data for protons on Li^7 were

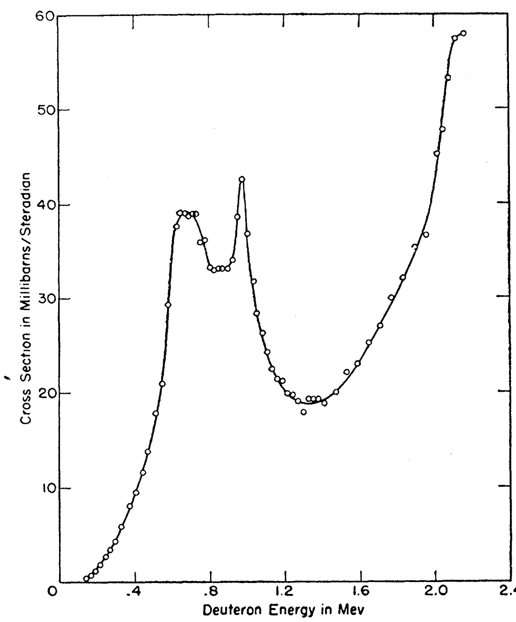

FIG. 2. Cross section for $Li^7(d,n)$ taken at 90±20 degrees to the deuteron beam. The data are uncorrected for Coulomb penetrability. The deuteron energy is that at the center of the target.

[6] R. F. Christy and R. Latter, Revs. Modern Phys. **20**, 185 (1948).

used, but since the charges are the same and the masses not far different, this will introduce only a small error. Curve B indicates the presence of two resonances. The lower energy resonance is in very good agreement with that found by Whaling and Bonner[2] in their alpha-particle and proton studies, when their data are corrected for penetrability in the above manner. However, their data for α-particle emission showed no indication of a second resonance. This indicates that the higher energy resonance is caused by p-deuterons and hence forbidden to alpha-particle disintegration. Since alpha-particles obey Bose-Einstein statistics, two alpha-particles produced in the decay of a Be^8 nucleus must have equal angular momentum, hence only excited states of Be^8 with an even angular momentum can decay by alpha-emission.

The cross section for neutron emission was measured at 868 kev both at 90±6 degrees and at 0±6 degrees to the deuteron beam. The values obtained with 15.0 millibarns per steradian at 90 degrees and 33.6 millibarns per steradian at 0 degrees.

2. Li^7

Figure 2 shows the neutron cross section for the reaction:

$$Li^7+H^2\rightarrow(Be^9)\rightarrow Be^8+n+15.0 \text{ Mev}$$

as a function of bombarding energy at 90±20 degrees to the deuteron beam. The data corrected for the Coulomb penetrability are not shown since the correction made an inappreciable change in either the position or the shape of the resonance. The excitation curve indicates the presence of three resonances. The lower two are in good agreement with those obtained by Bennett, Bonner, Richards, and Watt.[3] Whaling, Evans, and Bonner[1] observed the third resonance with the neutron detector at 0° at a lower energy.

The cross section for this reaction was also measured at 868 kev both at 90±6° and at 0±6° to the deuteron beam. The values obtained were 33.1 millibarns per steradian at 90 degrees and 48.3 millibarns per steradian at 0 degrees.

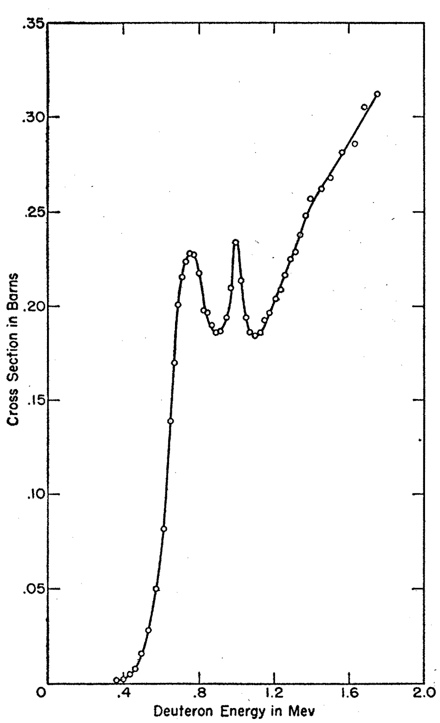

FIG. 3. Cross section for $Li^7(d,p)Li^8$.

TABLE I. Energy levels deduced from the experimental results.[a]

Nucleus	Position of resonance in Mev	Excited state in Mev	Width of level in Mev
Be^8	0.41	22.58	0.45
	2.12	23.86	0.15–0.20
Be^9	0.68	17.22	0.25
	0.98	17.45	0.060
	1.4	17.8	0.5
	2.1	18.3	0.4

[a] Energy levels were computed in terms of the masses given by Li, Whaling, Fowler, and Lauritsen, Phys. Rev. 83, 512 (1951).

3. Li^8

Figure 3 shows the variation with energy of the cross section for the production of beta-rays by the reaction:

$$Li^7+H^2\rightarrow(Be^9)\rightarrow Li^8+H^1-0.2 \text{ Mev},$$
$$Li^8\rightarrow {}^*Be^8+e^-+\nu+12 \text{ Mev}.$$

Since this reaction involves the same intermediate nucleus Be^9 as the reaction shown in Fig. 2, they should have a similar energy dependence. However, the excitation function for Li^8 obtained by Bennett, Bonner, Richards, and Watt[3] indicated that a resonance might possibly exist at 1.35-Mev deuteron energy. The curve of Fig. 3 is similar to the $Li^7(d,n)Be^8$ curve below 1 Mev, but it is quite different at higher energies. It shows a slight change of slope at about 1.4-Mev deuteron energy and does not go to as low a minimum following the second resonance as the curve of Fig. 2. This indicates the presence of a broad resonance at about 1.4 Mev.

IV. CONCLUSION

The excitation curves for Li^6 and Li^7 indicate the energy levels in Be^8 and Be^9 as shown in Table I.

The authors wish to acknowledge their indebtedness to Professor T. W. Bonner for his help and guidance throughout the course of this work.