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EXCITATION OF THE GROUND AND FIRST EXCITED STATES IN THE Li^6 (d,n) Be^7 REACTION

by

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(Euratom)

1963

Central Bureau for Nuclear Measurements
Geel Establishment (Belgium)

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EXCITATION OF THE GROUND AND FIRST EXCITED STATES IN THE Li^6(d, n)Be^7 REACTION

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Abstract: Results are reported on the angular distributions of the neutrons corresponding to the ground state and first excited state in the reaction Li^6(d, n)Be^7 for deuteron energies of 2, 2.5 and 3 MeV. Comparisons are made of the total cross sections with the results of the preceding paper on Li^6(d, p)Li^7 for the corresponding states to test charge symmetry in nuclear reactions. This comparison shows agreement in the ratio of the yields to the ground and first excited states within the experimental accuracy. Comparison is also made of the differential cross sections with a DWBA calculation. The agreement with the observed results, although consistent with $\Delta l = 1$, is poor in the back direction. Some evidence is presented which suggests the importance of compound nucleus effects in the Li^6(d, n) reaction.

1. Introduction

A study has been made of the excitation of the ground and first excited states of Be^7 in the reaction Li^6(d, n) to supplement the measurements described in a preceding paper [1]). The primary motivation of this work was to determine the ratio of the total yields to the two states for comparison with the ratio obtained for the mirror states in the reaction Li^6(d, p) as a test of charge symmetry.

2. Experimental

These measurements were made by the pulsed-beam-time-of-flight method using the Harwell 3 MeV pulsed Van de Graaff (Ibis) as the source of pulsed beam. The essential features of this system have been described previously [2]).

The detection system included the same essential elements used in a number of previous investigations [2]) but with the addition of a new discriminator and zero-crossing circuit [3]) using tunnel diodes. The purpose of this circuit is to minimize the "walk" effect, that is, the systematic variation in observed time due to the sensitivity of the time measuring apparatus to the amplitude of the pulse whose time of occurrence is being measured. This effect is frequently of major importance in determining the shape of a line in a time spectrum, particularly on the "late" side, where it contributes a prominent tail. In this work the tail structure is substantially reduced compared to that observed with otherwise similar apparatus, and the reduction so achieved contributed significantly to the accuracy of the results obtained.

† Guggenheim fellow.

Although the chief interest in these measurements was in a ratio of yields, it is necessary to know the relative sensitivity of the detector since the energy of the neutrons varies substantially with angle and deuteron energy. The sensitivity curve used was one which had been obtained previously [4]) for a proton-recoil scintillation detector of 4.4 cm diameter whose characteristics were reproduced as faithfully as possible. Several points of this calibration were spot-checked in the sensitive, low-energy region using the zero-degree yield of the T(p, n) reaction, and gave results in excellent agreement with those obtained previously.

The targets used were prepared by evaporation of lithium metal highly enriched with Li^6 on a tantalum backing; and to stabilize the target the nitride was then formed by exposing the target to a nitrogen atmosphere. Target currents in the range of 1 to 2 μA gave an ample yield at a detector distance of about 4 m.

Reproducibility of the results was limited by instability of the target under bombardment and this factor was the leading source of error in the measurements. To minimize this source of error and to provide a basis for estimating its magnitude the measurements were repeated on several occasions, and in any given run the data for adjacent angles were taken at different times. The errors assigned to individual points include estimates based on their departures from a smooth curve. The uncertainty in the mean energy assigned to each curve arises from the fact that the initial calibration of machine energy was made versus magnet current, so that it is necessary to include allowance for hysteresis effects.

3. Results and Discussion

Fig. 1 gives the relevant portion of the time spectrum for the two neutron groups of interest under the conditions least favourable for resolving them, that is, at zero degrees at the highest bombarding energy.

In estimating the relative intensity of the two groups a small and usually negligible uncertainty arises from the method of extrapolating the underlying background. The latter was identified as due in part to the activity of F^{17} formed by the (d, n) reaction in the oxygen contaminant of the target. Annihilation radiation and bremsstrahlung associated with the decay of F^{17} should contribute a background to which our detector is sensitive and which, on our time scale, should be random in time. It is evident, however, that there is also a synchronous component to the background which diminishes in the high energy direction. This was evident on many of the runs. Its identity has not been clearly established. The background extrapolation under the peaks was made by drawing a straight line connecting the backgrounds on each side of the pair of peaks.

Figs. 2-4 give the results for the angular distributions obtained in these measurements for the two groups of interest. Table 1 summarizes the results for the ratio of the yields for the two groups at each energy obtained by integrating the angular distributions with due allowance for solid angle. The integration was carried out over

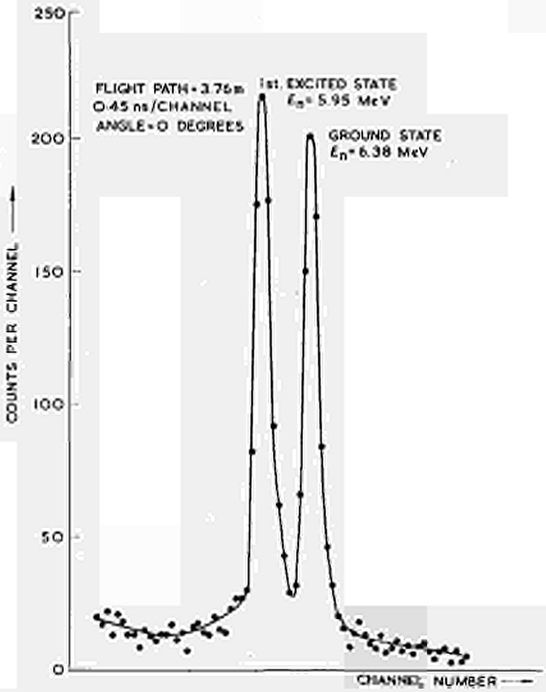

Fig. 1. Time spectrum showing the neutron groups observed at zero degrees corresponding to the ground and first excited states in the reaction $Li^6(d, n)Be^7$ for a bombarding energy of 3.0 MeV.

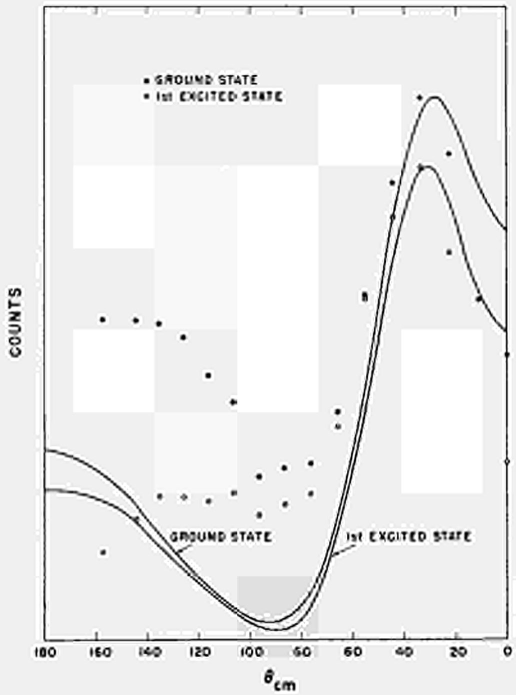

Fig. 2. Angular distributions of the neutron groups corresponding to the ground and first excited states, together with the result of the DWBA calculation (solid line), for a deuteron energy of 1.81 MeV.

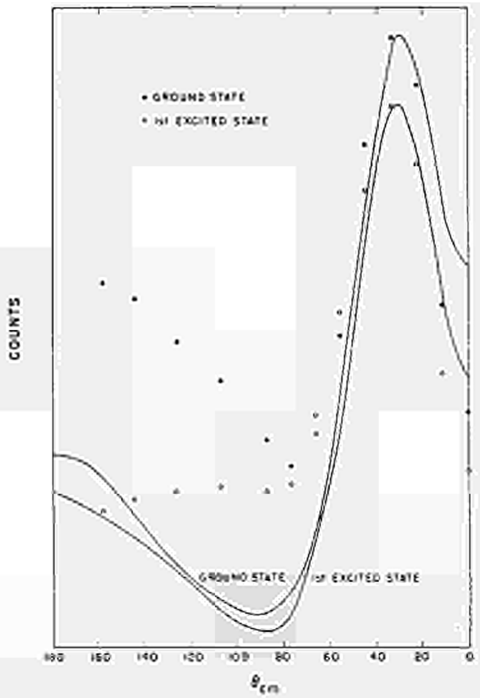

Fig. 3. Angular distributions of the neutron groups corresponding to the ground and first excited state, together with the result of the DWBA calculation (solid line), for a deuteron energy of 2.56 MeV.

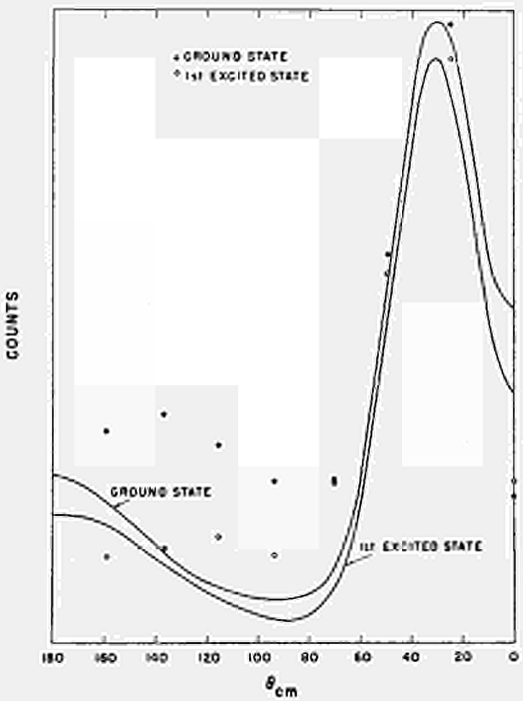

Fig. 4. Angular distributions of the neutron groups corresponding to the ground and first excited states, together with the result of the DWBA calculation (solid line), for a deuteron energy of 3.08 MeV.

smooth curves drawn through the data points. Agreement with the neutron results of the previous paper is satisfactory.

Although the primary interest of this investigation was in the ratio of total cross sections, the availability of codes [5]) for calculating the differential cross sections by the distorted wave Born approximation method suggested that a comparison with

TABLE 1

Ratio of the yields

Average deuteron energy (MeV)	Target thickness (keV)	Ratio n/n^*
1.81 ± 0.050	44	1.40 ± 0.03
2.56 ± 0.050	40	1.38 ± 0.03
3.08 ± 0.050	17	1.30 ± 0.04

the calculation should be attempted. The curves drawn in figs. 2-4 give the results of the calculations for $\Delta l = 1$ compared with the experimental data points. The values of the parameters used in the calculations, which are defined in ref. [5]), are given in table 2. The curves have been normalized to the experimental points at the maxima. Although the positions of the maxima are in good agreement with the positions of the experimental maxima the fits are in general poor, particularly for the larger angles and lower energies, suggesting the importance of reaction mechanisms other than stripping.

TABLE 2

Optical model parameters used in DWBA calculation

Particle	V (MeV)	W (MeV)	r_0 (fm)	a (fm)
d	60	8	2.1	0.65
n	50	10	1.3	0.5

The chief significance of these results from the point of view of the primary purpose of this investigation – namely, a comparison of the ratio of yields for ground and first excited states for the two mirror reactions has been discussed in the previous paper. It may not be inappropriate at this point, however, to make a few supplementary remarks. One aspect of the Coulomb correction, whose role remains to be quantitatively assessed, is that the mirror reactions can excite different levels in the residual nucleus for the same bombarding energy. Thus, for the Li^6(d, n) reaction only the $\frac{7}{2}^-$ level at 4.53 MeV can be excited in competition with the ground and first excited states at the highest bombarding energy used. For the Li^6(d, p) case, however, there can be competition from the level at 6.54 MeV as well as energetically more favourable conditions for excitation of the mirror state at 4.63 MeV. These states presumably have spins of $\frac{5}{2}$ and $\frac{7}{2}$, respectively [6]). It seems reasonable to expect that this asymmetry between the two reactions could affect the observed ratios differently. In particular one might expect that in the (d, p) case the $\frac{3}{2}^-$ ground state would have more competition than the $\frac{1}{2}^-$ first excited state from the higher lying high angular momentum states. If this argument is correct the ratio n/n^* to p/p^* might be expected to be somewhat larger than unity. There is a small but systematic indication that this may be so (see preceding paper).

It seems clear from these results and the results reported in the preceding paper that improvements can be readily achieved in the accuracy with which the ratio n/n^* has been determined by more careful attention to the conditions wich affect the stability of the target. On the other hand it would seem preferable first to have a theoretical formulation which relates the ratios in a quantitative way to charge symmetry.

The marked backward peaking, particularly for the neutrons corresponding to the ground state, has already been commented upon in the preceding paper, and the suggestion has been made that heavy-particle stripping may be responsible. It is noted here that compound nucleus effects may also be responsible. Recently [7]) measurements have been made of the angular distributions of the neutrons corresponding to the same two states excited in the reaction Li^7(p, n)Be^7 at an excitation in the compound nucleus Be^8 which is the same as that reached in the measurements reported here, i.e. about 24 MeV. In the (p, n) reaction at this excitation the neutrons exhibit near-symmetry about 90 degrees in the C.M. system, suggesting the predominance of compound nucleus formation in that reaction. The angular distributions obtained for the neutron groups corresponding to the ground and first excited state are very similar to the results obtained here in the Li^6(d, n) reaction in the back direction. That is, the ground state group shows backward peaking and the first excited state group is relatively flat. Furthermore, if we compare the relative yields of the two Li^6(d, n) neutron groups in the back direction, where stripping should make a relatively small contribution, to the corresponding ratio for the Li^7(p, n) reaction (table 3), we see a similar trend. Correction for the backward contribution from stripping would improve the agreement. Quantitative superposition of the effects of compound nucleus formation and stripping would, however, require consideration of possible interference effects.

TABLE 3

Comparison of n/n^* from Li^6(d, n) and Li^7(p, n) at back angles at corresponding excitation in Be^8

Centre-of-mass angle (degrees)	n/n^* Li^6(d, n) $E_d = 2.5$ MeV	n/n^* Li^7(p, n) $E_p = 8$ MeV (ref. [7])
100	1.6	1.99
120	2.0	2.3
140	2.4	2.9
160	3.2	3.8

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