Energy Spectrum of Alpha Particles from Li^7+d at $E_d=1.0$ Mev*

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The high-energy part of the alpha spectrum emitted in the bombardment of Li^7 with deuterons, was measured with a magnetic spectrometer at $E_d=1.0$ Mev and $\theta=90°$. For the $Li^7(d,\alpha)He^5$ (ground state) reaction, a Q value of 14.11 ± 0.08 Mev is obtained. The spectrum yields level parameters for the ground state of He^5 which are consistent with those known from n-α scattering data. No definite evidence for an α group corresponding to an excited state of He^5 was found.

INTRODUCTION

WHEN Li^7 is bombarded with deuterons, one of the possible nuclear processes[1] is the formation of two α particles and a neutron. This transformation may either proceed via a (d,α)[2–4] or a (d,n)[5] reaction with the formation and subsequent decay of levels in He^5 or Be^8, respectively:

$$Li^7(d,\alpha)He^5;\quad He^5\to He^4+n; \tag{I}$$

$$Li^7(d,n)Be^8;\quad Be^8\to He^4+He^4. \tag{II}$$

The α particles leading to the ground state of He^5 have been identified by Cüer and Jung[2,3] and by Levine, Bender, and McGruer.[4] The Q values obtained by both groups of workers were in rough agreement with an excitation energy of 0.95 Mev as found from other reactions.[1,6] Cüer and Jung,[2] using nuclear emulsion technique with partial magnetic separation, also report an α group corresponding to an excited state in He^5, 2.5 ± 0.2 Mev above the ground state. Evidence for the He^5 first excited state had previously been obtained in He^4+n elastic scattering experiments.[6] Angular distributions consistent with the shell model assignments $^2P_{\frac{3}{2}}$ and $^2P_{\frac{1}{2}}$ for the ground state and the first excited state respectively have been observed in $Li^6(n,d)$ experiments.[7] The angular correlations between the two alpha particles[8] are also consistent with a $^2P_{\frac{3}{2}}$ assignment for the ground state but do not yield any direct information about the He^5 excited state.

The groups from the (d,α) reaction are superimposed on a broad continuum, which is composed of the contributions from the decay of He^5 and from reaction (II). The direct formation of α particles by three-body breakup probably contributes also to the spectrum.

It seemed worthwhile to try a better separation of the groups from the continuum by using a different technique.

EXPERIMENTAL ARRANGEMENT

The present measurement of the alpha spectrum was carried out with a high-resolution magnetic spectrometer, using sufficiently thin targets to permit easy detection of any fine structure. The target was prepared by evaporating natural metallic lithium on a thick tantalum foil. The lithium was then allowed to react with air for several hours in order to form LiOH throughout the layer. This target was exposed to the electrostatically analyzed deuteron beam of a Van de Graaff generator. The spectrometer was set to accept particles emitted at a laboratory angle of 90° with respect to the direction of the incoming deuterons. A CsI crystal at the exit slit of the spectrometer served as particle detector, allowing discrimination between α particles, deuterons, and protons. A deuteron energy of 1 Mev with a spread of less than 0.3% was used. A target thickness of 24 kev was found for 1-Mev deuterons by observing the shift of the scattering edge when the target was replaced by clean tantalum. The resolution of the spectrometer was $E/\delta E=230$.

RESULTS

The magnetic spectrum of the alpha particles, i.e., the number of counts $N(I)$ *versus* the magnetometer setting $I(\sim1/P)$ is shown in Fig. 1. Besides the strong peak at 21.7 mv, which corresponds to the ground state of He^5, there is hardly a deviation from a monotonic decrease with increasing I. In order to compare the results with those from the nuclear emulsion work,[2] the energy spectrum, i.e., $dN(E)/dE\sim N(I)\times I^2$ *versus* E, is shown in Fig. 2.

The circles correspond to the experimental points of Fig. 1. The peak corresponding to the He^5 ground state occurs at 8.12 Mev, yielding a Q value for the $Li^7(d,\alpha)He^5$ (ground state) reaction $Q_1=14.11\pm0.08$ Mev. The dashed pattern represents the data of Jung and Cüer[2] measured at $E_d=0.98$ Mev, and $\theta=90°$.

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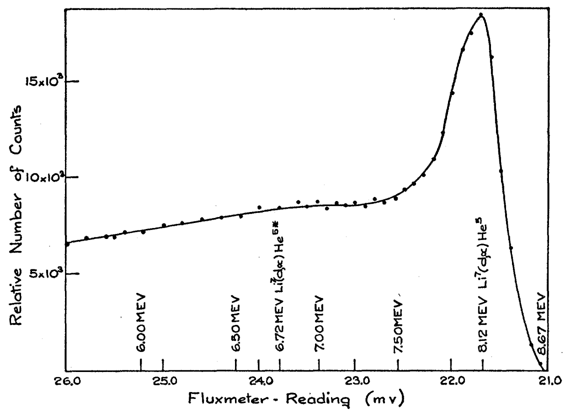

FIG. 1. The magnetic spectrum of alpha particles from Li^7+d at $E_d=1.0$ Mev and $\theta=90°$. The fluxmeter reading is inversely proportional to the momentum of the alpha particles. The points at which groups from the $Li^7(d,\alpha)He^5$ reaction are expected according to the known Q values, are indicated.

Their Q value, $Q_1=14.2\pm0.1$ Mev, agrees within the limits of error with the present measurement. There is also rough agreement with the results of Levine, Bender, and McGruer[4] who find $Q_1=14.26\pm0.09$ Mev at $E_d=14.4$ Mev. The solid curve represents the theoretical spectrum of the α particles emitted in the formation of the He^5 ground state, corrected for the energy loss in the target. This curve is derived as follows. If one assumes the (d,α) reaction to proceed via a compound state in Be^9, the relative probability of the α particle to be emitted with an energy E is given by the probability of Be^9 for α decay to the He^5 ground state times the density of final states, i.e.,

$$\frac{dN(E)}{dE}\sim\Gamma_\alpha(Q_1)\frac{\Gamma_n(Q_2)}{(E_{\frac{3}{2}}+\Delta_{\frac{3}{2}}(Q_2)-Q_2)^2+(\frac{1}{2}\Gamma_n(Q_2))^2};\quad(1)$$

where

$$Q_1+Q_2=15.11\text{ Mev};\quad E=(5/9)Q_1+(1/3)E_d,$$

Q_1 and Q_2 are the Q values for the reactions $Li^7(d,\alpha)He^5$ and $He^5\rightarrow He^4+n$, respectively; $\Gamma_\alpha(Q_1)$ and $\Gamma_n(Q_2)$ are the corresponding partial widths. $E_{\frac{3}{2}}$ is the level energy of He^5, and $\Delta_{\frac{3}{2}}(Q_2)$ the energy dependent level shift. Γ_α will depend on the spin J of the compound state and its energy dependence will be different for different values of the orbital angular momentum l_α. In a rigorous representation of the spectrum, Γ_α will be replaced by a sum of terms, each having a different energy dependence. The angular correlation experiment at $E_d=0.93$ Mev of French and Treacy[8] suggests $J=\frac{3}{2}$ and both s and d waves for the emitted α particles. Because of the high energy of the α particles (≈8 Mev), the barrier penetration factors[9] for $l_\alpha=0$ and $l_\alpha=2$ vary very little over the energy range of interest. For simplicity, the energy dependence of Γ_α was completely neglected in fitting Eq. (1) to the experimental points of Fig. 2. The solid curve was obtained with the following parameters for the He^5 ground state: $\gamma^2=1.76\times10^{-12}$ Mev cm, $a=2.9\times10^{-13}$ cm, $E_{\frac{3}{2}}=2.70$ Mev, where the channel radius and the reduced width were chosen to agree with the values used by Adair[10] in the analysis of the n-α and p-α scattering experiments. The "resonance energy" as given by $Q_{2R}=\Delta_{\frac{3}{2}}(Q_{2R})+E_{\frac{3}{2}}=1.09$ Mev does not agree with the energy value Q_2 corresponding to the experimental maximum of the spectrum, because of the strong variation of Γ_n with Q_2. From the Q_1 of the (d,α) reaction as discussed above, one finds $Q_2=1.0\pm0.05$ Mev for the He^5 ground state. The error arises mainly from the uncertainty of the contribution to the spectrum from the three-body breakup, which has been completely neglected in the above analysis. So far, the three-body breakup has not been found experimentally, but from the large s-wave contribution to the n-α scattering,[10] it seems possible that the contribution from this process amounts to about 10% of the peak counting rate.

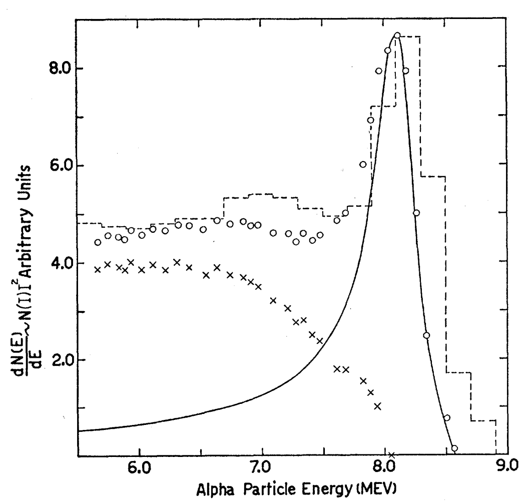

FIG. 2. The energy spectrum of the alpha particles. The circles represent the experimental points of Fig. 1. The solid curve is the theoretical α spectrum of the $Li^7(d,\alpha)He^5$ (ground state) reaction given by expression (1). The crosses give the difference between the ordinates of the circles and the corresponding ordinates of the curve. The dashed pattern represents the data of Jung and Cüer[2] measured at $E_d=0.98$ Mev and $\theta=90°$.

There is definite disagreement of the data near $E=7$ Mev, where a peak occurs in the dashed curve, but none is indicated by the circles. The continuum, i.e., the experimental points with the corresponding ordinates of the solid curve subtracted, is represented by crosses in Fig. 2. There is no direct indication of a group in the region of 6.5 Mev. However, the possibility of a weak α group of an experimental width of the order of 1–2 Mev centered around 6.5 Mev cannot be

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excluded. The possibility that a relatively sharp group has been smeared out experimentally can be discarded, because of the small thickness of the target and the high resolution of the spectrometer. The reactions $Li^6(d,\alpha)He^4$ and $Li^6(d,He^3)He^5$ do not yield α particles which could contribute to the spectrum in the energy range observed. Delayed α particles from the decay of Be^8 levels formed via $Li^7(d,p)Li^8-\beta^-\rightarrow Be^8$ would have been easily identified, but none were observed.

The shape of the alpha spectrum at $\theta=90°$ has been studied at several other deuteron energies up to $E_d=2.2$ Mev. No group, except the one belonging to the He^5 ground state was found; i.e., the spectra had essentially the shape given in Fig. 1.

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Measurements of (n,α) Cross Sections at 14 Mev

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Results of activation measurements of the (n,α) cross section of nine isotopes ranging in mass number from 59 to 133 are reported. The measurements were made at a neutron energy of 14 ± 0.5 Mev using neutrons from the $D(t,n)He^4$ reaction. The cross sections show a markedly different dependence on mass number from that reported in a previous survey.

INTRODUCTION

In a previous paper[1] (hereinafter referred to as BGHR), results of activation measurements of the (n,α) cross sections of the isotopes Zn^{68}, Zr^{90}, Zr^{94}, and In^{115} were reported. The cross-section values obtained in BGHR differed widely from the trend reported in a previous survey[2] (hereinafter referred to as PC), but since only four cross sections were measured, it was not possible to state conclusively whether the values obtained represented a new and different general pattern for (n,α) reactions, or whether they represented simply unusually large statistical fluctuations about the trend reported in PC. In the present paper, results of five additional (n,α) cross-section measurements are presented; these, together with the four measurements previously reported, indicate a trend substantially different from that reported in PC. Cross-section values obtained are typically about a factor of two lower than in PC at $A\approx60$, and the factor gradually increases to about twenty at $A\approx135$.

EXPERIMENTAL TECHNIQUE

As in BGHR, cross-section measurements were of a relative character, the actual measured quantity being the ratio of the (n,α) cross sections to the $Fe^{56}(n,p)$ cross section. From these cross-section ratios absolute values are derived assuming a value of 110 mb for the $Fe^{56}(n,p)$ cross section at 14 Mev. This value for the $Fe^{56}(n,p)$ cross section is an established mean value[3] based on measurements by PC (96.7 mb$\pm$12%) and by Forbes[4] (124 mb$\pm$10%). Subsequent to the establishment of the value given by reference 3, a measurement by Yasumi[5] (144 ± 19 mb) has been reported. On the basis of reported measurements, the assumed value of 110 mb could be in error by +50% or by −20%, yielding a corresponding possible error in the absolute value of the cross sections reported herein. Errors given in the results are errors in the relative values only; any subsequent measurements of $Fe^{56}(n,p)$ leading to the firm establishment of a value different from 110 mb would require an appropriate change in the scale factor of all the cross sections herein reported. The relative relationships of the cross sections would, of course, be unaffected.

The substantial uncertainty in the absolute value of the calibration cross section is unfortunate; on the other hand, the detailed studies by Terrell and Holm[6]

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.
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