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THE Li^6 $(d, \alpha)\alpha$ REACTION

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Abstract: The $Li^6(d,\alpha)\alpha$ reaction has been studied up to 5 MeV deuteron energy. A new level in Be^8 at 25.3 MeV excitation is observed having probably $J = 2^{\pm}$ and T = 0.

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1. Introduction.

The $Li^6(d, \alpha)\alpha$ reaction has been studied by Heydenburg et al [1] up to about 3.5 MeV of incident deuteron energy. They observed a resonance around 800 KeV deuteron energy having a laboratory width of about 800 keV. The angular distribution for this level showed the existence of other interfering levels. Recently Heydenburg et al [2] had observed a resonance around 5.5 MeV proton energy in the $Li^7(p, \alpha)\alpha$ reaction with an unresolved level at around 6 MeV. They also observed a resonance with a small yield compared to the 5.5 MeV resonance, at around proton energy of 9.0 MeV. The present work was undertaken to extend the (d, α) study to 5 MeV deuteron energy in order to investigate the properties of the alpha emitting states around 20 MeV excitation in Be^8.

2. Experimental Technique.

The $Li^6(d,\alpha)\alpha$ reaction was studied from 1 MeV to 5 MeV deuteron energy using the Van de Graaff machine at Saclay. The targets were 99.6% enriched Li^6 metal deposited on 10 $\mu gm/cm^2$ carbon backing. The Li^6 metal was evaporated on to the backing and was allowed to remain in air for some period till it turned into the hydroxide. The target thickness was around 10 $\mu gm/cm^2$.

The scattering chamber is described elsewhere [3]. Excitation curves for 12 angles from 85° to 165° in the laboratory system were obtained using solid state counters to detect the alpha particles emitted from the reaction. A solid state detector at 90° was used as a monitor throughout the experiment.

3. Results.

Figure 1 shows the excitation curves at the various angles. These curves were normalized for target deterioration using the monitor counts. The points on the curve have a total error of 5% which comprises of the counting statistics of the detector and the monitor and the experimental errors in charge measurement, fluctuations in the electronics etc. From these excitation curves the angular distributions were obtained at various energies and were fitted the by least squares method to a polynomial of the form $A_o(1+A_2P_2(x)+A_4P_4(x))$ where $P_2(x)$ and $P_4(x)$ are Legendre polynomials of the second and fourth order, and $x = \cos\theta$. These analysis were all done on IBM 7090 at Saclay.

Typical angular distribution curves are shown in fig. 2. These curves were normalized to unit monitor reading. The solid curves in this figure are the theoretical fits obtained from the least squares analysis.

The variation of the coefficient A_2 and A_4 with energy are shown in fig. 3 where the earlier data of Heydenburg et al[1] are also plotted for comparison. The errors on these coefficients are of the order of 5-10%.

The total excitation curve is shown in fig. 4 where the data of Heydenburg et al, normalized to our values, are also indicated.

4. Discussion.

The resonance that we observed at a deuteron energy of 3.7 MeV corresponds to the small resonance observed at around 9 MeV in the $Li^7(p,\alpha)\alpha$ reaction by Heydenburg et al [2]. The angular distribution around this resonance has a maximum complexity of P_4 only as given by our χ^2 analysis. The 800 keV resonance in the (d, α) reaction also shows a small P_4 component and has a large P_2 component in the angular distribution. In fig. 6 we present the complete excitation curve for the $Li^7(p,\alpha)\alpha$ reaction up to a proton energy of 12 MeV and for the $Li^6(d,\alpha)\alpha$ reaction up to a deuteron energy of 5 MeV for the laboratory angle of 90°, as functions of the excitation energy in Be^8 in order to compare the various resonances obtained in the two reactions. These curves have been obtained by normalizing Heydenburg et al's data (cf. ref. 2) to our data up to 5 MeV (cf. ref. 7) for the $Li^7(p,\alpha)\alpha$ reaction. One sees from this curve that the 800 keV resonance observed in the $Li^6(d,\alpha)\alpha$ reaction corresponds to the 6 MeV resonance in the $Li^7(p,\alpha)\alpha$ reaction. In fig. 5 we give all the known alpha emitting states in Be^8 including the present data.

It is well known that the two low lying states at 2.9 MeV with $J = 2^+$ and at 11.9 MeV with $J = 4^+$ together with the ground state ($J = 0^+$) can be explained on the cluster model.[8] The large widths for these states which approximate to Wigner limit for the α-particles forces one to picture these states as pure α particle states. One is tempted to extend this picture to the other α-emitting states in Be^8. We give below some qualitative arguments to show that these states around 20 MeV cannot be regarded as originating from alpha clusters.

The 19.9 MeV state corresponding to the 3 MeV resonance in the $Li^7(p,\alpha)\alpha$ reaction has a peak cross-section of about 130 millibarns and a total width of about 1 MeV. The angular distributions for this level indicate that it has $J = 2^+$. On the assumption that this is as single level with no interference from any other level (this assumption is not strictly valid as shown below), one obtains for the reduced widths a value of 0.05 MeV for the alphas and 0.23 MeV for the protons. These correspond to 6% of the Wigner limit for both the alphas and the protons. These values will not materially change even if one takes into account interference from others 2^+ resonances since they were obtained by fitting the region of the total cross--section curve where the contributions from the interference terms are assumed small. Furthermore the ratio of the number of protons to the number of alpha particles emitted in the $Li^6(Li^6, \alpha)\ Be^{8*}$ reaction [9] seems not incompatible with the above values. From this analysis we thus obtain $\Gamma_p = 0.24$ MeV, $\Gamma_\alpha = 0.76$ MeV which yields $(\Gamma_p/\Gamma_\alpha) \simeq 1/3$.

Recently Temmer [10] gave a value of $\Gamma_n : \Gamma_p : \Gamma_\alpha = 75:25:1$ for this level. This ratio cannot fit the observed cross-section. Also the $Li^7(p, p)Li^7$ and $Li^7(p, n)Be^7$ reactions [11] have a large cross-section in this region and do not exhibit in the excitation curve any pronounced peak. Both the $Li^7(p,p)Li^7$ and $Li^7(p,n)Be^7$ reactions indicate the presence of a very broad state around 3 MeV possibly having $J = 1^{\pm}$ [11]. The large (p,α) cross-section supports this view and we think that the 19.9 MeV level is composed of two supersimposed levels one of which has $J = 2^+$ and the other $J = 1^{\pm}$.

Our analysis of the angular distributions for the 19.9 MeV states indicates the presence of interfering levels below and above this resonance. Experiments using polarized protons [12] tend to confirm this view. Their data agree with Christy's [13] suggestion of a 2^+ level around zero proton energy.

From the value of the α-reduced width for this level we see that the 19.9 state is not an alpha state. Most probably it is a two particle excitation state in Be^8. Whether it has a large probability for deuteron clusters is not obvious from either the $Li^7(p,\alpha)\alpha$ data or the $Li^6(Li^6,\alpha)Be^{8*}$ data.

The 5.5 MeV resonance in the $Li^7(p,\alpha)\alpha$ reaction has a peak cross-section of 7.5 mb/ster. at $\theta_{LAB} = 90°$ compared to 12.5 mb/ster. for the 3 MeV resonance. Since the proton and the alpha penetrabilities do not change very much from 3 to 5 MeV proton energy, and since the angular distributions for these two states are not very different, all the above arguments are equally well applicable to this resonance also.

The 800 keV resonance in $Li^6(d,\alpha)\alpha$ reaction has a peak cross-section of 70 millibarns. At the laboratory angle of 90°

it has a cross-section of about 5.5 mb/ster. compared to 3 mb/ster. for the 6 MeV resonance of $Li^7(p,\alpha)\alpha$ reaction. If one assumes that the total cross-section is essentially equal to $4\pi\sigma(90°)$ which is approximately true in this case, we get $(\sigma_p/\sigma_d) \approx 0.5$. Since the ratio of proton to deuteron penetrability for this resonance is ~ 4 we obtain for the ratio of the reduced widths $\left(\gamma_p^2/\gamma_d^2\right) \simeq 1.1$. By arguments similar to those presented above one can show that $\gamma_\alpha < \gamma_d$ for this resonance. Hence one sees that this resonance is not a pure alpha or deuteron cluster.

The 9 MeV resonance in the $Li^7(p,\alpha)\alpha$ reaction has a peak cross-section of about 1 mb/ster. compared with 4.5 mb/ster. for the $Li^6(d,\alpha)\alpha$ reaction at $\theta_{LAB} = 90°$. If one assumes the ratio of the total cross-section to be the same as the ratio at 90° for these reactions, we obtain $(\sigma_p/\sigma_d) \approx 0.2$. Since the ratio of the penetrabilities for the proton to the deuteron is ≈ 1.3, we get $\left(\gamma_p^2/\gamma_d^2\right) \simeq 1/5$ (Note that the cross-section ratios have a factor $\pi\lambda^2$ depending on the mass and energy of the incident particle). One can definitely state that for this resonance the deuteron width is very large and hence it may possibly have a large probability for deuteron - Li^6 parentage.

Recently Temmer [14] has made the suggestion that the 19.9 MeV state, the 22.15 MeV state and the 25.3 MeV state in Be^8 are $Li^6 + d$ clusters. On his model one predicts also a 4^+ state around 23.6 MeV. We see no indication of such a state in the $Li^6(d,\alpha)\alpha$ reaction unless it is submerged in the large background between the two resonances at 800 keV and 3.7 MeV. The arguments given above do not contradict Temmer's assumption.

It is very interesting that around 22 MeV excitation in Be^8 one has so many 2^+ states. Three of these states can possibly be understood on Temmer's model which still leaves at least two levels unexplained. Further work in this region, especially the study of $Li^6(Li^6, \alpha)Be^{8*}$ reaction is needed to clarify the situation.

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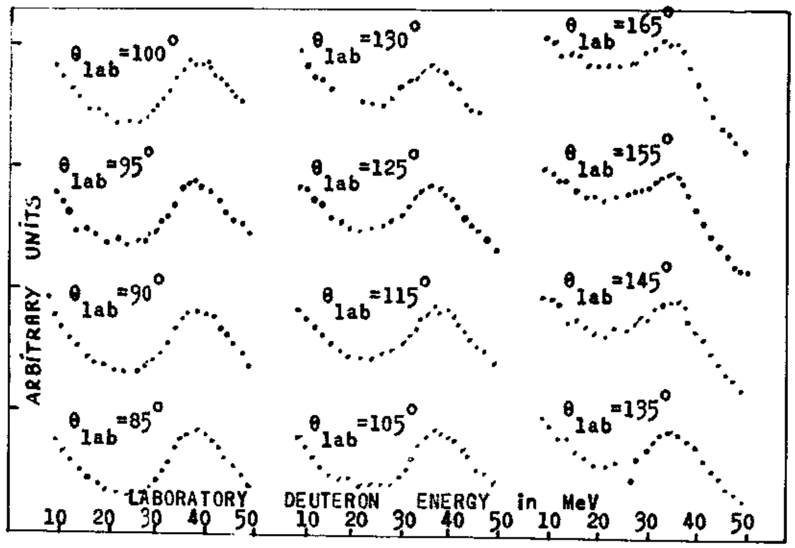

Fig. 1: Corrected excitation curves of $Li^6(d,\alpha)\,\alpha$ reaction for various laboratory angles.

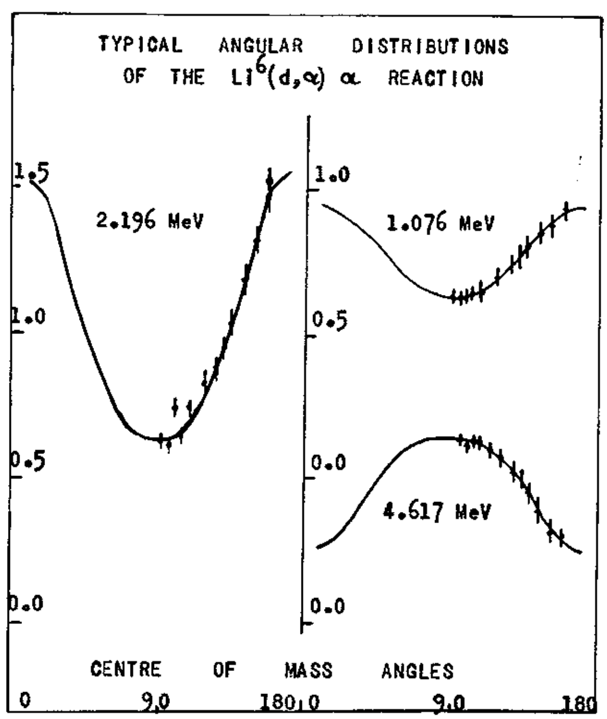

Fig. 2: Typical angular distribution curves for CM angles for the $Li^6(d,\alpha)\,\alpha$ reaction.

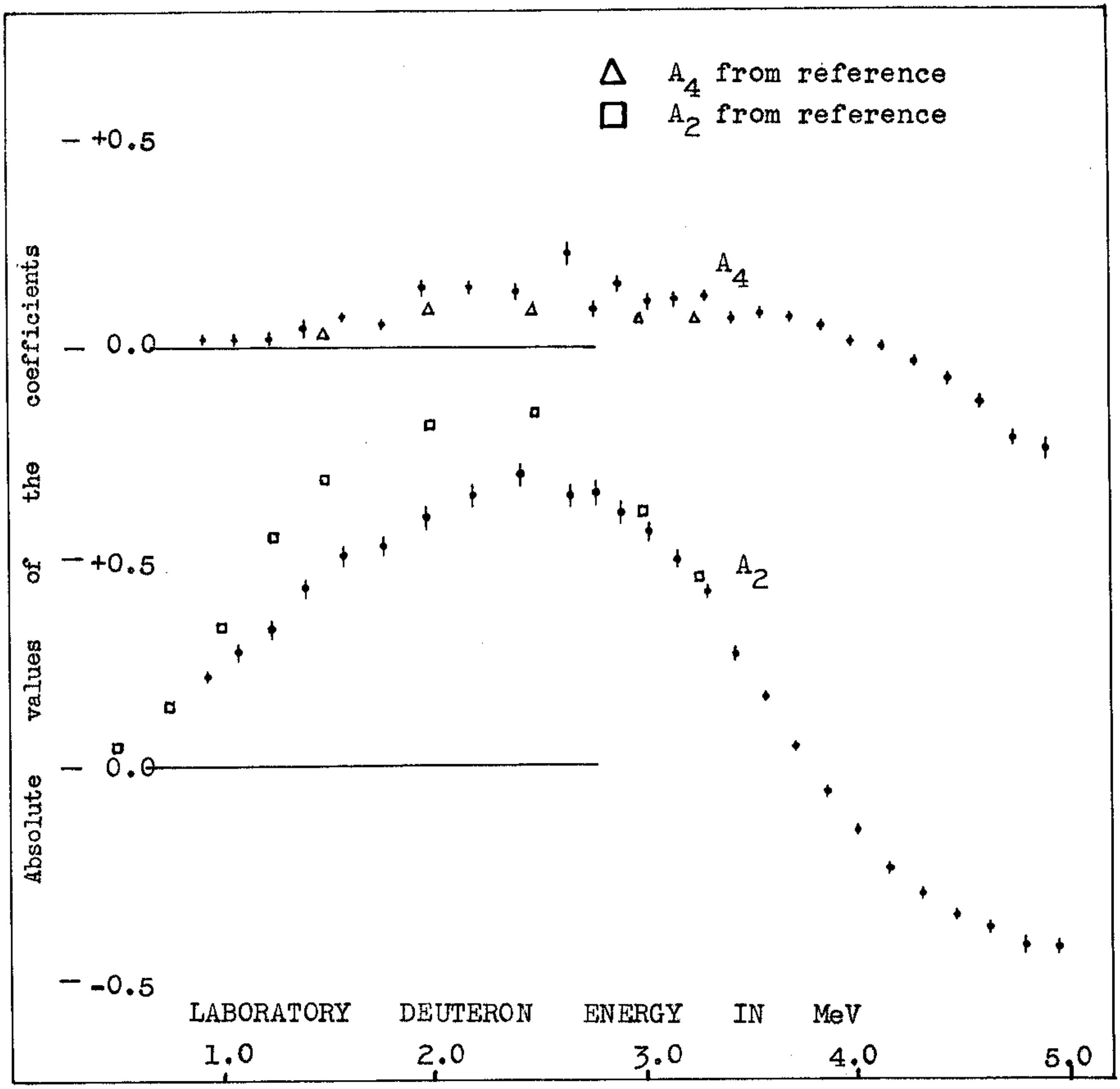

Fig. 3: Values of the coefficients A_2 and A_4, obtained by fitting the equation $A_o\ (1 + A_2P_2(\cos\theta) + A_4P_4(\cos\theta))$ to the experimental angular distributions, as a function of the incident deuteron energy in the laboratory system.

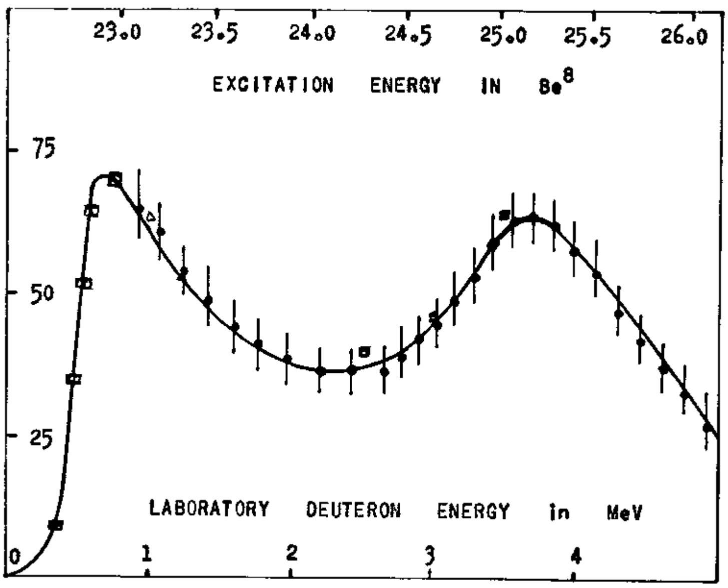

Fig. 4: Total excitation curve of the $Li^6(d,\alpha)\alpha$ reaction.

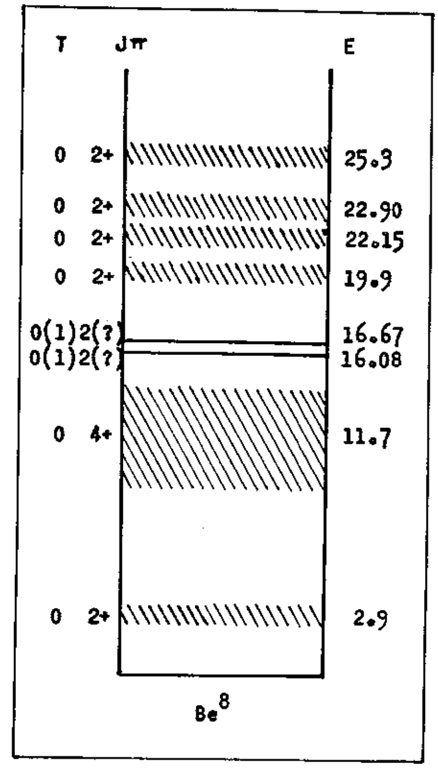

Fig. 5: The alpha emitting states of Be^8 (note: Most probably either 16.67 or 16.08 MeV state is 2^+, T = 0 and hence alpha emitting. The other one is possibly 2^+, T = 1. It is also quite possible that either or both of these states have large isotopic spin mixing).

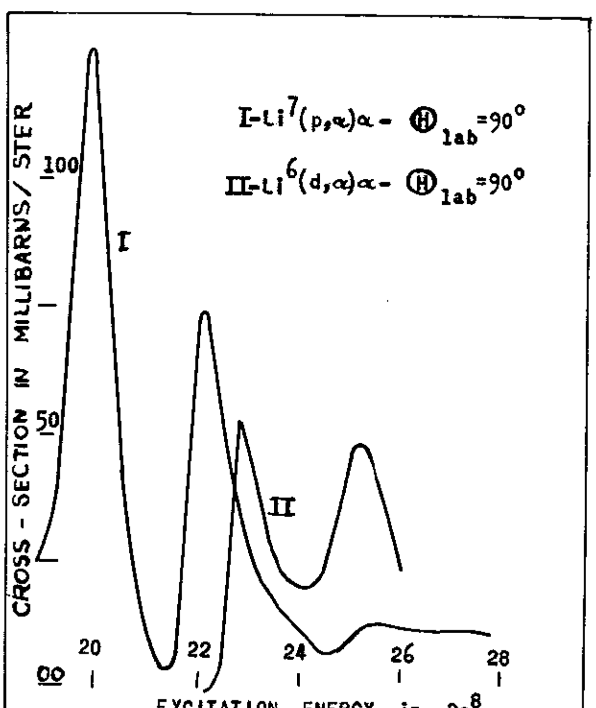

Fig. 6: Comparison of the excitation curves for $Li^7(p,\alpha)\alpha$ and $Li^6(d,\alpha)\alpha$ reaction as functions of excitation energy in Be^8 for $\theta_{LAB} = 90°$.