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ON THE $^{13}D_1$ $^6$Li STATE AT ABOUT 5.7 MeV EXCITATION ENERGY (x)

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ABSTRACT.

The $\alpha$-$d$ bidimensional spectra for the $^7$Li($^3$He, $\alpha$ad) reaction at $E_{3He} = 5$ MeV and at various detection angles have been measured. The peak corresponding to an $\alpha$-$d$ relative energy of about 5.7 MeV, found in the spectra, has been analyzed. By taking this peak to be mainly contributed by the $^{13}D_1$ $^6$Li state at 5.7 MeV, an estimate of the excitation energy and width of this state is given.

The existence of a $^6$Li state with $J^\pi = 1^+$, $T = 0$ at an excitation energy of about 5.7 MeV, spectroscopically indicated with the notation $^{13}D_1$, has been evidenced by the phase shifts analysis of the $d$-$^4$He elastic scattering (1-3). However, if one excludes the Allen's experiment (4), the contribution of this state is not clearly discernible in any one of the particle spectra measured in the kinematically incomplete experiments carried out on the $^7$Li ($^3$He, $\alpha$ad) and $^6$Li(p, $\alpha$ad) reactions (5, 6), which produce the $^6$Li nucleus as a result of the $\alpha$-$d$ interaction in the final state. In fact, due to the large background and the high yield peak from the 5.37 MeV $^6$Li state, the contribution of the $^{13}D_1$ state is obscured in the above mentioned spectra.

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Although the low T = 0 admixture in the 5.37 MeV state forbids the decay of this state in the a-d channel, the 13D₁ state contribution is not clearly seen even in the a-d or p-a spectra measured in the kinematically complete experiments performed on the same reactions (7-10). Thus while some authors only mention the 13D₁ state contribution as a shoulder in their spectra, others do not mention it at all. The most explicit outline of the above state is found in the work of Von Wiśniewski et al. (9). Although the 13D₁ state contribution is not evident enough even in their spectra, these authors give an estimate of its excitation energy and width.

In order to attempt to evince the contribution of this state at the best we decided to perform a systematic study of the ⁷Li(³He, a+d) reaction. We began by measuring the a-d bidimensional spectra with the two detectors arranged in the ordinary left-right geometry and by using a ³He bombarding energy of 5 MeV, an energy where no kinematically complete experiment has been performed on the ⁷Li(³He, a+d) reaction until now.

The Fig. 1 shows the used experimental apparatus. The 5 MeV ³He beam was produced by the 7.5 MV Van de Graaff accelerator of the Legnaro National Laboratories. The ⁷Li target, obtained by evaporating LiF (99.9 % enriched in ⁷Li) onto a carbon backing of 40 μg/cm², was 0.5 mg/cm² thick. The detector 1, fixed at θ₁ = 90° and φ₁ = 0°, was a telescope consisting of a totally depleted solid state detector 100 μm thick and a surface barrier solid state detector 1000 μm thick; the ΔE detector, while stopping the a-particles, let the deuterons pass. This prevented the a-a events detection and has simplified the data analysis. The surface barrier solid state detector 2 was allowed to rotate between θ₂ = 10° and θ₂ = 170° at φ₂ = 180° and its 300 μm thick depletion region stopped all the a-particles produced in the reaction. In order to measure correctly the deuterons energy and at the same time to reduce the effects of energy straggling suffered by the deuterons in ΔE detector, the pulses produced in ΔE and E detectors were summed by the Σ circuit. A triple fast-slow 30 ns resolving time coincidence circuit was set up to gate a 4096 channels analyzer and a remarkable reduction of the random coincidences was obtained in the bidimensional spectra measured.

We observed in several of these spectra, in addition to two well-defined events groups corresponding to the formation of the ⁸Be at the ground state and at its first excited state, a third one which kinematically could be contributed by the a-d final state interaction in the ⁶Li states at excitation energies between 5 and 6 MeV. Because, as it was said before, the isospin forbids the decay of the 5.37 MeV ⁶Li state into the a-d channel, and our search for contaminations which eventually could contribute gave a negative result, we thought the above third
group to be attributable to the 5.7 MeV $^{13}\text{C}^1$ $^6\text{Li}$ state indicated by the phase shifts of the d-$^5\text{He}$ elastic scattering. Thus we decided to analyse the measured spectra.

The most suitable way of treatment of a bidimensional spectrum data is to project them on an axis or a curve of the $E_1$-$E_2$ plane. There are different reasons which indicate that the central kinematical curve (the one corresponding to the angles defined by the beam direction and detectors axes) is a good choice as a projection locus. In fact both the finite angular and energetic resolutions of the detecting system contribute to the spreading of the events on the $E_1$-$E_2$ plane. Therefore if the true distribution of events has to be extracted from the projected data, before projecting them, the geometrical effects have to be separated from the energetic ones.

Obviously this is not needed when the angular resolution is good with respect to the energetic one. In such a case all the events can be considered as belonging to the central kinematical curve and it is correct enough to project all of them on such a curve. This condition is best satisfied in our experiment at $\theta_1 = 90^\circ$ and $\theta_2 = 45^\circ$ detector angles. To perform the projection of the data we used the method developed by some of us et al.\textsuperscript{(11)}. By assuming that the finite overall energetic resolution of the detecting system produces a lorentian spreading, the method, while projecting the data, automatically operates a sort of deconvolution on them. Thus it produces a distribution of the events on the kinematical curve which should be a good approximation to the true one.

![Diagram](image)

**FIG. 2** - Distribution of counts along the kinematic curves at various angles for the $^7\text{Li}$($^5\text{He}, \alpha$)d reaction at $E_{^5\text{He}} = 5$ MeV: a) $\theta_1 = 90^\circ$, $\theta_2 = 40^\circ$; b) $\theta_1 = 90^\circ$, $\theta_2 = 45^\circ$; c) $\theta_1 = 90^\circ$, $\theta_2 = 80^\circ$. The curve $E_{2,3}$ refers to the $\alpha$-$\alpha$ system relative energy and the curves $E_{1,2}$ and $E_{1,3}$ refer to the d-$\alpha$ system relative energy. s is the arc length of the rectified kinematic curve.
Fig. 2 shows the results of the projection of the laboratory system data from the $\theta_1 = 90^\circ$, $\theta_2 = 40^\circ$, $45^\circ$, $80^\circ$ experiments, after target energy loss corrections have been done. As one can see, in addition to two well-defined maxima due to ground state and 2.9 MeV state in $^8$Be, in all of the projected spectra appears a well-resolved peak which at the maximum corresponds to a relative energy for the $\alpha-$d system of about 5.7 MeV. In order to extract the above peak maximum energy position and width, which should correspond to the excitation energy and width of the $^{13}\text{D}_1$ $^6$Li state within the limits in which the peak is attributable to this $^6$Li state, we reduced the data from $\theta_1 = 90^\circ$ and $\theta_2 = 45^\circ$ experiment in the Relative Coordinate System (RCS). We fitted them separately with two Breit-Wigner distributions by using the least-squares method. The first fit was done on the data between 2 and 3 MeV $\alpha-$d relative energy and gave for the excitation energy and width of the 2.9 MeV $^8$Be state respectively the values $E_x = 2.85 \pm 0.2$ MeV and $\Gamma = 1.46 \pm 0.3$ MeV. The second one was done on the data between 4 and 8 MeV $d-$d relative energy, i.e. on the data which correspond to the peak that is of our interest.

Fig. 3 reports the above last data in the RCS. The continuous curve represents the Breit-Wigner fit. This fit gave for the maximum energy position and width of the peak the values $E_x = 5.7 \pm 0.2$ MeV and $\Gamma = 1.65 \pm 0.3$ MeV respectively. The errors take into account both the statistical errors and the finite energy resolution of the analysing system.

The value of $E_x$ is in quite good agreement with the excitation energy value recently assigned to the $^{13}\text{D}_1$ $^6$Li state by the d-$^4$He elastic scattering study\(^{(12)}\). On the contrary, as far as the width value is concerned, such a good agreement is not met\(^{(9)}\).

It is difficult to estimate the confidence limits of the method used by us to extract the above parameters from the data. We wish, however, to point out the values of $E_x$ and $\Gamma$ found for the 2.9 MeV $^8$Be state to be in satisfactory agreement with the ones in literature.

We think it necessary to continue the study of the $^7\text{Li}(^3\text{He}, \alpha d)$ reaction for two reasons. The first one is that to evaluate to which extent the 5.37 MeV $^6$Li state contributes to the peak. The second one is to study the population change of the $^{13}\text{D}_1$ state by varying the $^3$He bombarding energy.
REFERENCES.