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Width of the level at $E_x \simeq 18$ MeV in ^{5}Li

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The $\alpha\alpha$ bidimensional spectra for the ^{6}Li(^{3}He, αp)^{4}He reaction at 11, 13, and 14 MeV incident energy have been measured. The ^{5}Li state at $E_x = (17.9 \pm 0.4)$ MeV has been observed and its width has been determined as (3.5 ± 0.8) MeV. The excitation energy is in line with the shell-model calculations while the Γ value is the first quantitative estimate of the width of the above state.

I. INTRODUCTION

The least known of the ^{5}He and ^{5}Li states with even parity and $T = \frac{1}{2}$ are the ones at an excitation energy of about 18 MeV,[1] despite the fact that the shell model, applied to the $A = 5$ systems, predicts for both nuclei a $J^\pi = \frac{1}{2}^+$, $T = \frac{1}{2}$ state at the above-mentioned excitation energy.[2]

Whereas for the ^{5}He there is no experimental evidence of this state, it appeared necessary to invoke its existence in the case of ^{5}Li to interpret some experimental results obtained from α-p and ^{3}He-d scattering experiments. In particular, the analysis of the phase shifts of the elastic αp scattering, at energies between 25 and 29 MeV, indicates a resonance of $J^\pi = \frac{1}{2}^+$ at an excitation energy of about 18 MeV.[3] Nearly simultaneously to this result, other authors[4] carried out a ^{3}He(d,p)^{4}He experiment at incident energies between 2.8 and 11.5 MeV, and found that the Legendre polynomial expansion coefficients for the differential cross section depend on the energy. They also observed some anomalies in the energy behavior of these coefficients with incident energy, attributing this effect to the presence of the above-mentioned ^{5}Li state. Finally, the analysis[5] of γ_0 and γ_1 emitted in the ^{2}H(^{3}He,γ)^{5}Li reaction, at incident energies between 2 and 26 MeV, is consistent with a $\frac{1}{2}^+$ state in ^{5}Li placed near the 18 MeV excitation energy. Accordingly, in this evaluation[1] the existence of a broad level with an excitation energy between 17 and 19 MeV in ^{5}Li is accepted, while nothing appears as far as the mirror nucleus ^{5}He is concerned.

In the spectra of the above-mentioned experiments this ^{5}Li state is presumably obscured by the neighboring resonances; therefore to better resolve it we used the ^{6}Li(^{3}He,$\alpha\alpha p$) reaction in which it is produced as an intermediate state in the first stage of the reaction, which is presumed to proceed via a sequential mechanism. This investigation, at incident energies between 11 and 14 MeV, was mostly undertaken in order to excite the ^{5}Li states in the region which encompasses the predicted state with $J^\pi = \frac{1}{2}^+$, $T = \frac{1}{2}$, and to determine its width.

The ^{6}Li(^{3}He,α)^{5}Li reaction has already been studied at an incident energy of 25.5 MeV (Ref. 6), and spectra of α particles have been analyzed in respect to the high-lying ^{5}Li states. These spectra showed two resonances roughly centered at 19.8 and 22.7 MeV, besides the ground state and the well-known state at $E_x = 16.66$ MeV. We believe that the state at $E_x = 18$ MeV was not identified in these spectra because the ^{5}Li contributions appeared as very weak fluctuations superimposed on a strong background. In order to overcome this problem, we decided to study the $\alpha\alpha$ bidimensional spectra of the ^{6}Li(^{3}He,αp)^{4}He reaction which forms ^{5}Li in the intermediate state that later decays into the α-p channel.

II. EXPERIMENTAL PROCEDURE

The ^{3}He beam of 11, 13, and 14 MeV was produced by the 7.0 MV Van de Graaff accelerator of the National Laboratories in Legnaro (Padova). The ^{6}Li target was obtained by evaporating LiF (99.9% enriched in ^{6}Li) onto a carbon backing of 20 μg/cm^2 and was about 50 μg/cm^2 thick. The surface barrier detector 1.100 μm thick, could rotate around the target in the $\varphi_1 = 0°$ plane. The surface barrier detector two, 100 μm thick, was fixed at $\vartheta_2 = 90°$ in the $\varphi_2 = 180°$ plane.

The choice of the thickness of the detectors, which stopped the protons up to ~ 3 MeV and α particles up to ~ 13 MeV, was carried out in order to have the region of interest free of αp and $p\alpha$ coincidences. The experimental apparatus was the same as the one described in a previous work.[7]

The linear pulses were analyzed by being sent to the analog-to-digital converter inputs of the data acquisition system, through two linear gates. These were gated by the pulses developed at the output of a time-to-pulse-height-converter single-channel-analyzer system when the timing signal reaching its inputs occurred within an 80 ns time.

We measured the energy of the two α particles and the time-of-flight difference by means of a standard fast-slow electronic setup. The ^{3}He current was about 60 nA and each measurement run took roughly 8 h.

The best way of treating the bidimensional spectrum data is to project them onto an axis or curve of the (E_1,E_2) plane. Various factors show that the central kinematic curve (the one corresponding to the angles defined by the beam direction and detector axes) is a good projection locus. Both the finite angular and energy resolution of the detecting system contribute to the spreading of the events of the (E_1,E_2) plane, so if we are to extract the true distribution of events from the projected data, we must separate the geometrical effects from the energy ones before projection. This is not necessary, however, when the angular resolution is quite good. Indeed, in this case, all the events can be considered to belong to the central kinematic curve of the three-body ^{6}Li(^{3}He,αp)^{4}He reaction. By assuming a Lorentzian spreading due to the finite overall energy resolution of the detecting system, the projected data can be automatically deconvoluted from the effects of the finite-energy resolving power of the experimental apparatus. Therefore, it produces a distribution of events on the central kinematic curve which ought to be a good approximation of the true one.[8,9]

III. RESULTS AND DISCUSSION

Figures 1–3 show some of the spectra obtained in our experiment after projection of the data onto the kinematical curve, and after target energy loss corrections have been carried out. Spurious coincidences were reduced to such a low level to be considered negligible by selecting off-line a 10 ns window for the time-of-flight difference of the coincidence events. In the same figures the excitation energies (E_{1-3} and E_{2-3}) and (E_{1-2}) for the αp and $\alpha\alpha$ systems, respectively, are displayed versus the curvilinear abscissa s. As one can see, the distributions of $\alpha\alpha$ counts show a well-defined peak followed by a shoulder.

The peak corresponds to the contribution of the 16.66 MeV ^{5}Li state, while the marked shoulder kinematically corresponds to the contribution of the ^{5}Li at the (17–19.5) MeV excitation energy range. In the above-mentioned energy range, there are no contributions coming from other ^{5}Li states, while the insufficiently high ^{3}He bombarding energy and the high spin of the 11.4 MeV ^{8}Be state do not allow a significant formation of the latter,[10,11] which could be the only kinematically allowed ^{8}Be state. Therefore, in order to separate the two contributions and to obtain the position and width of the ^{5}Li state which we are interested in, we used the MINUIT code. The same code provided the yield of the state corresponding to the interval where the shoulder falls with respect to the yield of the 16.66 MeV ^{5}Li state. Once one assigns the peak energy and width values given in literature[1] for this state, the code performs an autoconsistent calculation and gives as a result of the fit the normalization constants for each state and the values of the width and E^* position for the shoulder contribution, as we did previously.[12] If one neglects the interference effect due to the identity of the particles, and one assumes that the event distribution in each peak can be represented by a Lorentzian form in the relative coordinate system (RCS), the code allows us to determine the position and width of the contribution of our interest.

Figures 1–3 show the results of a fit (dotted curves), where a width of 300 keV was assumed for the 16.66 MeV state in ^{5}Li. The values of the positions and their width for all the spectra reported in Figs. 1–3, as deduced

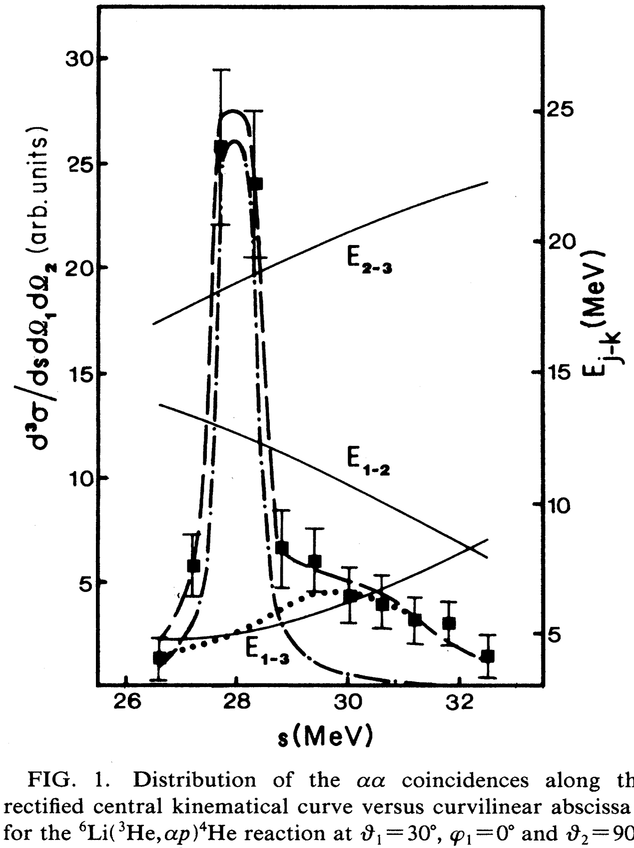

FIG. 1. Distribution of the $\alpha\alpha$ coincidences along the rectified central kinematical curve versus curvilinear abscissa s for the ^{6}Li(^{3}He,αp)^{4}He reaction at $\vartheta_1=30°$, $\varphi_1=0°$ and $\vartheta_2=90°$, $\varphi_2=180°$ and $E(^3\mathrm{He})=11$ MeV. The E_{1-3}, E_{2-3} refer to the relative energy of αp, while E_{1-2} refers to the relative energy of the $\alpha\alpha$ system. The dashed-dotted line represents the 16.66 MeV ^{5}Li state contribution. The dotted line represents the 17.9 MeV ^{5}Li state contribution. The dashed line represents the fit resulting from the sum of the two above-mentioned contributions.

by the fitting procedure, are summarized in Table I. The best estimate for the excitation energy and width of the studied ^{5}Li state is $E_x = (17.9 \pm 0.4)$ MeV, and $\Gamma = (3.5 \pm 0.8)$ MeV, obtained as a weighted average of the values reported in the table. The estimated errors for the spectra take into account both the statistical errors and the finite-energy resolution of the electronic system used.

In this experiment, the $\frac{1}{2}^+$ state at 18 MeV in ^{5}Li has been singled out in a better and more reliable way than in the previous experiments. This improvement may be, above all, related to the coincidence technique, which essentially suppresses all the background in experimental spectra, and leaves prominent contributions of $\frac{3}{2}^+$ and $\frac{1}{2}^+$ states, which are to be deconvoluted. In addition, the conditions for the production of the latter state in the

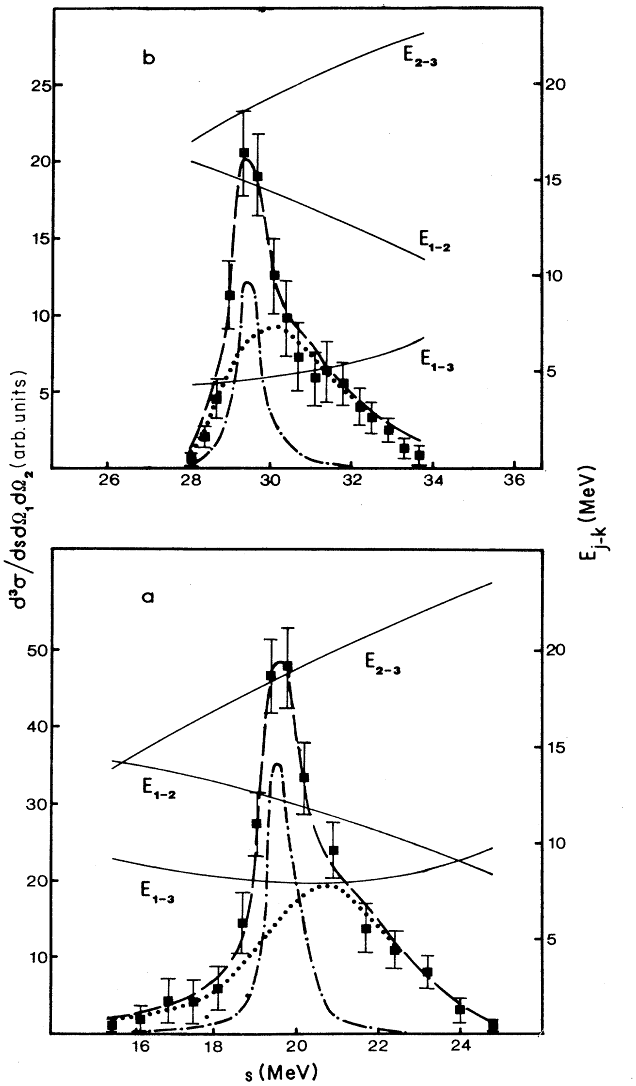

FIG. 2. Same as Fig. 1 but with $E(^3\text{He}) = 13$ MeV and (a) $\vartheta_1 = 20°$, $\vartheta_2 = 90°$; (b) $\vartheta_1 = 30°$, $\vartheta_2 = 90°$.

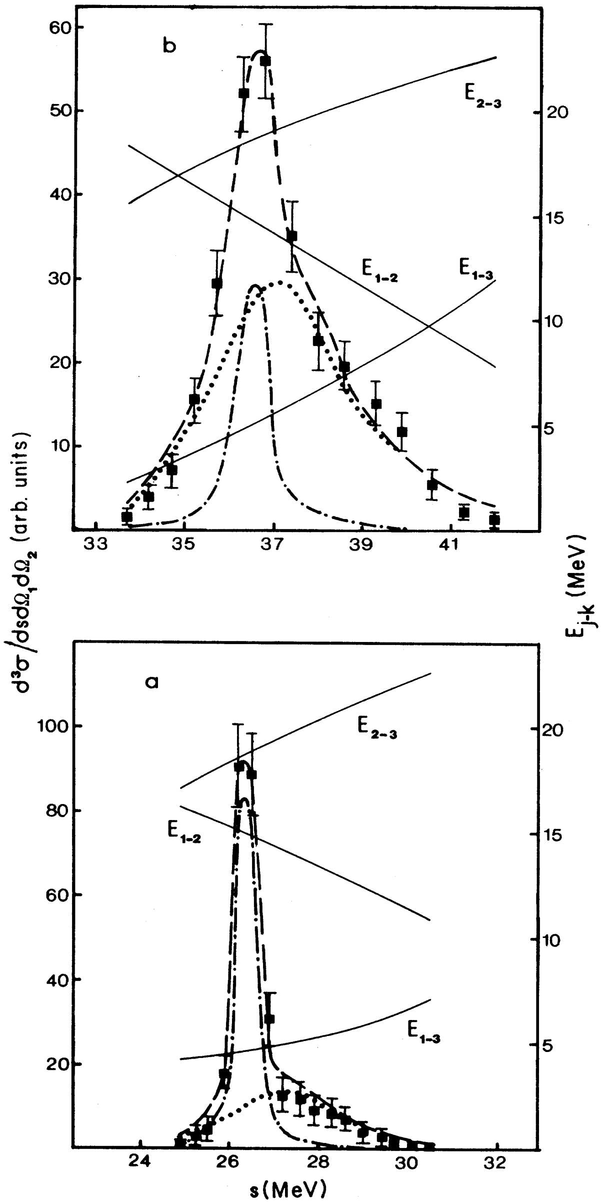

FIG. 3. Same as Fig. 1 but with $E(^3\text{He}) = 14$ MeV and (a) $\vartheta_1 = 30°$, $\vartheta_2 = 90°$; (b) $\vartheta_1 = 50°$, $\vartheta_2 = 90°$.

TABLE I. Experimental results for the energy and width of the ^{5}Li level at $E_x \simeq 18$ MeV.

E_{inc} (MeV)	ϑ_1 (deg) $\varphi_1 = 0°$	ϑ_2 (deg) $\varphi_2 = 180°$	E_x (MeV)	Γ (MeV)
11	30	90	18.3 ± 0.5	3.9 ± 1.0
13	20	90	17.8 ± 0.3	3.8 ± 0.7
13	30	90	17.7 ± 0.4	3.8 ± 0.9
14	30	90	17.9 ± 0.3	3.2 ± 0.7
14	50	90	17.7 ± 0.3	3.4 ± 0.6

three-body reaction might possibly be somewhat more favorable than in the two-body processes. We note that the large width of the state under discussion makes experimental investigations relatively difficult; hence previous experiments did not provide convincing proof of its existence. As far as theoretical predictions are concerned, there is at present no possibility of performing a microscopic calculation for the $A = 9$ system with three fragments in the exit channel. Even the theoretical estimate of the width of the level is beyond the present capability. This only allows some qualitative considerations. If it is true that the investigated state in ^{5}Li as spin $\frac{1}{2}$ and positive parity, we could expect contributions from three possible bifragmented structures: $\alpha + p$ in the relative S state, and ^{3}He$+d$ in the relative S or D state. The large width observed seems to favor the S-state hypotheses, since the centrifugal barrier should delay the D-state structure decay, thereby resulting in a smaller width of the level. Therefore the fact that in our experiment the level is observed in the $\alpha + p$ channel may indicate a substantial contribution of this fragmentation (first hypothesis) to the level structure. On the first hand, a rough evaluation of the c.m. system angular distribution contributions for the 18 MeV ^{5}Li state, over a wide set of spectra, suggests that this resonance occurs mainly in the s wave.

In conclusion, while the excitation energy value confirms the shell-model predictions[2] for $A = 5$ systems and agrees with the indications deduced from recent experimental works,[3–5] our result represents the first quantitative estimate of the width of the 17.9 MeV in ^{5}Li.

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