^{6}Li levels excited by the ^{9}Be(p,α) reaction at $E_p=30$ and 50 MeV

Th. Delbar and Gh. Grégoire
Institut de Physique Corpusculaire, Louvain-la-Neuve, Belgium

G. Paić
Institut Rudjer Bošković, Zagreb, Yugoslavia
(Received 9 August 1982)

The levels of the ^{6}Li nucleus were studied via the ^{9}Be(p,α) reaction at incident proton energies of 30 and 50 MeV. Accurate excitation energies as well as some of the corresponding widths are extracted for the first few levels known. Marked differences with accepted values were found. The existence of higher excited states in the region $E_{\rm exc}=8-12$ MeV cannot be ruled out. The aim is not to study reaction mechanisms leading to ^{6}Li excited states but rather to establish their excitation energies and widths and to compare them to the published values. The importance of understanding the continuum in the particle spectra is stressed as far as it influences the position and width of the excited states.

[NUCLEAR REACTIONS ^{9}Be$(p,\alpha)^{6}$Li, $E_{\rm lab}=30$, 50 MeV. Measured alpha particle spectra; continuous spectra; phase space model; deduced excitation energies and widths; comparison with previous values.]

I. INTRODUCTION

Since the ^{6}Li nucleus is one of the lightest nuclei with a known sequence of excited levels the knowledge of its level parameters (position, width and structure) is of importance in testing present models as well as N-N and N-α potentials.[1–3]

In general, the theoretical predictions are in fair agreement with the experimental results for the first six levels up to ~ 6 MeV excitation. However, above this limit the calculations predict the existence of a $^{1}P_1$ $T=0$ state and of a $^{3}P_{0,1,2}$ triplet of $T=1$ states in the excitation region below 15 MeV.

On the experimental side an extensive number of experiments were performed:

(a) d-α scattering for the study of $T=0$ excited states.

(b) ^{3}He-t scattering for the study of $T=0$ and $T=1$ levels above the ^{3}He-t breakup threshold in the ^{6}Li nucleus (15.8 MeV).

(c) Reaction or inelastic scattering processes in which the residual ^{6}Li nucleus is left excited. Below 15.8 MeV excitation, this mode of observation is the only one open for the measurement of the $T=1$ levels.

The reaction channels allow, of course, the study of the parameters of the $T=0$ levels as well.

When a comparison is made between the level parameters extracted from phase shift analysis and those obtained through different reaction channels one observes a large dispersion in the parameters reported, e.g., the quoted width of the 4.3 MeV level ranges from 0.3 to 1.82 MeV.[4]

The dispersion may be due to the fact that the extraction of level parameters is complicated for all levels but the three first ones ($E_x=0$, 2.18, and 3.56 MeV) since (a) there is a considerable overlap between the levels due to their widths, (b) they are superimposed on a continuum due to nonresonant processes, and (c) the extraction of the level parameters necessitates assumptions about the structure of the level, as will be shown later.

In this work our interest is not the reaction mechanism which has been the subject of many previous papers,[5] but rather the spectroscopy of the residual nucleus ^{6}Li. We try to evaluate both the statistical and the systematic errors on the level parameters in order to arrive at meaningful comparisons with compiled data.[4] The analysis of the energy spectra was made assuming a nonarbitrary background under the peaks, and the peak profiles are assumed to be functions of the internal structure of the resonant states.

II. EXPERIMENT

The ^{9}Be$(p,\alpha)^{6}$Li reaction was measured at $E_p=30$ and 50 MeV using the analyzed proton beam of the variable energy cyclotron CYCLONE of the University of Louvain. The measurements were performed at $\theta_\alpha = 10$, 20, 25, 30, 35, 40, 50, and 60 degrees (laboratory) at $E_p = 30$ MeV, and 10, 15, 20, 25, 30, 40, 50, and 60 degrees (laboratory) at $E_p = 50$ MeV.

The ^{9}Be target was a self-supported evaporated foil 380 μg/cm^2 thick.

The charged particles were detected by a conventional ΔE-E surface barrier telescope with a veto counter behind the E detector to prevent overloading of the analog-to-digital converters (ADC's) by signals from long range light particles. The thickness of the ΔE detector fixes our threshold energy at 4.5 MeV at $E_p = 30$ MeV, and 13 MeV at 50 MeV incident proton energy. The telescope was fixed on a turntable rotating around the target. The accuracy of the detection angle was about 0.1°. The solid angle was 7×10^{-5} steradians and the angular aperture was 0.3 degrees. Each detector was connected to a standard preamplifier-spectroscopy amplifier chain, the output of which was fed into a 4096 channel analog-to-digital converter. The E and ΔE information was recorded event by event on magnetic tapes for off-line analysis. The deadtime was monitored continuously with random pulser events.

The identification was made by drawing separation curves in the two-dimensional ΔE-E plot. The separation between α and ^{3}He particles was such that 0.04% of ^{3}He events could be counted as alphas. The contributions to the experimental resolutions are given in Table I. We list the smallest and largest values of each contribution.

The energy calibration and the evaluation of systematic errors are particularly important since we are interested in the excitation energies and widths of the residual nucleus. The energy calibration was based on the positions of the ground state and the 3.56 MeV excited state of ^{6}Li taken at all measured angles. It was corrected for the energy losses of the incident protons and outgoing alphas in the target. The uncertainty (at the one standard-deviation level) of the energy calibration relative to the ground state of ^{6}Li is 5 keV. This method of calibration excludes systematic errors. We present here their evaluation at $E_p = 30$ MeV, but the same conclusions are valid at $E_p = 50$ MeV.

(a) An unrealistic error of 1 MeV on the beam energy would not induce any error in the position of levels up to 10 MeV in ^{6}Li since all detected particles will have the same energy shift of 813 keV.

(b) An unrealistic systematic error on the detection angle of 0.5° will introduce a relative shift of levels (within the 10 MeV excitation range) of less than 2 keV.

(c) A 10% error on the target thickness will result in a translation of the calibration curve with nonlinear effects of the order of 1 keV.

(d) The angular distribution of the levels used for the calibration can also induce an error due to the detector aperture. It is about 0.3 degrees in our case. However, due to the shape of the measured angular distribution the sign of this effect would be angle dependent. Such a behavior was not observed in the calibration.

(e) The error induced by a possible nonlinearity of the electronics has not been observed in the large energy range used for the calibration.

III. EXTRACTION OF LEVEL PARAMETERS

To extract the level parameters we have simultaneously fitted the nonresonant continuum spectrum and the resonant levels. For the sake of clarity we shall explain separately the method used to

TABLE I. Contributions to the resolution σ (keV) of the α peak belonging to the ^{9}Be$(p,\alpha)^6$Li$_{\text{g.s.}}$ reaction at $E_p = 30$ and 50 MeV.

Origin of σ	$E_p=30$ MeV $\sigma^{*a}_{\min}$	$E_p=30$ MeV $\sigma^{*a}_{\max}$	$E_p=50$ MeV $\sigma^{*a}_{\min}$	$E_p=50$ MeV $\sigma^{*a}_{\max}$
Beam spread	5 (60°)	7 (10°)	6 (90°)	9 (10°)
Solid angle	7 (10°)	24 (60°)	10 (10°)	39 (60°)
Finite size of the beam on target	3 (10°)	55 (60°)	4 (10°)	89 (60°)
Target thickness	40 (10°)	63 (60°)	26 (10°)	82 (90°)
Detector	14	14	14	14
Beam divergence	≤ 10 (10°)	≤ 34 (60°)	≤ 13 (10°)	≤ 55 (60°)
Electronics[b]	<78	<78	<84	<84
Observed σ	81	112	73	156

[a]The numbers in parentheses denote the angle at which the minimum or maximum occurs.
[b]The quoted contributions of the electronics are upper limits.

describe the nonresonant and resonant parts of the energy spectra.

A. Nonresonant continuum spectrum

In the framework of the phase space model (PSM), we have shown[6] that the continuum spectrum of the ^{9}Be(p,α) reaction above 13 MeV excitation in ^{6}Li is well reproduced by an incoherent sum of phase space spectra due to the nonresonant breakups in the final state. At a given angle of detection, such a treatment implies that the matrix element $T_{\rm if}$ between the initial and final state can be averaged and treated as a constant independent of the momenta of the undetected particles.

In its general form, the differential cross section for particle N in a reaction

$$A(a,m_N)m_1m_2\cdots m_{N-1}$$

is given by

$$\frac{d^2\sigma}{d\Omega_N dT_N}=\frac{2\pi p_N m_N}{v_0\hbar^4}\int\frac{d^3k_1}{(2\pi)^3}\cdots\int\frac{d^3k_{N-1}}{(2\pi)^3}\,|T_{\rm if}|^2\delta\left[\vec{k}_0-\sum_{i=1}^{N}\vec{k}_i\right]\delta\left[T_0-\sum_{i=1}^{N}T_i\right], \tag{1}$$

where T_i, p_i, and m_i are the kinetic energy, the linear momentum and the mass of particle i, respectively, and v_0 is the velocity of the incident particle.

In the phase space model, $|T_{\rm if}|^2$ is replaced by its mean value $C_i\equiv\langle |T_{\rm if}|^2\rangle$ and brought outside the integral. Formula (1) becomes

$$\frac{d^2\sigma}{d\Omega_N dT_N}=\frac{2\pi p_N m_N}{v_0\hbar^4}C_iR_{N-1}(m_1,m_2,\ldots,m_{N-1};T^*,P^*)\,. \tag{2}$$

R_{N-1} is the phase space factor of the $(N-1)$ undetected particles sharing a total kinetic energy T^* and a total linear momentum P^*:

$$R_{N-1}(m_1,m_2,\ldots,m_{N-1};T^*,P^*)=D_{N-1}\left[T^*-\frac{P^{*2}}{2\sum_{i=1}^{N-1}m_i}\right]^{(3N-8)/2}, \tag{3}$$

$$D_N=\frac{1}{h^{3(N-1)}}\frac{(2\pi)^{[3(N-3)]/2}}{\Gamma[\frac{3}{2}(N-1)]}\frac{\left[\prod_{i=1}^{N}m_i\right]^{3/2}}{\left[\sum_{i=1}^{N}m_i\right]^{3/2}}\,. \tag{4}$$

B. Shape of the peaks corresponding to excited levels

For the ^{9}Be$(p,\alpha)^6$Li reaction the peaks corresponding to the particle stable states (ground state and 3.56 MeV) shall have a roughly Gaussian shape with a width equal to the experimental resolution.

For particle unstable levels the spectral shape is also given by formula (1) but $|T_{\rm if}|^2$ cannot be treated anymore as a constant.

One may say that in its most general form $|T_{\rm if}|^2$ can represent a resonance between N free particles. However, one usually restricts the analysis to resonances between two clusters (or quasiclusters like, e.g., ^{5}He$+p$). Then $|T_{\rm if}|^2$ can depend on the relative energy of the particles in the final state, on their relative angular momentum, as well as on the total energy available to the spectrum.

In a sequential picture of the formation and decay of a resonant state one may factorize $|T_{\rm if}|^2$ into a production matrix element $|T_{\rm if}|_F^2$ and a matrix element $|T_{\rm if}|_R^2$ describing the resonant interaction of $(N-1)$ particles in the final state.

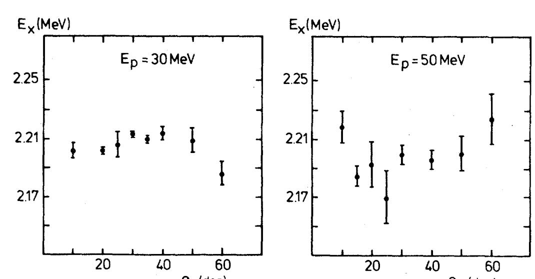

FIG. 1. Position of the 2.185 MeV $(3^+,0)$ level extracted from the ^{9}Be$(p,\alpha)^6$Li measurements at different angles for $E_p=30$ and 50 MeV.

In our calculations $|T_{if}|_F^2$ will be approximated by a constant as in the phase space model. It can therefore be extracted out of the integral in relation (1).

$|T_{if}|_R^2$ is taken to be of the Breit-Wigner form:

$$|T_{if}|_R^2 = \frac{\Gamma^2/4}{(E-E_0)^2+\Gamma^2/4} , \qquad (5)$$

where E_0 is the energy of the resonance in the center of mass system of the interacting particles; E is accordingly the total energy of the same particles determined at each point in the energy spectrum. For computational ease $|T_{if}|_R^2$ is not normalized since we are interested only in the shape of the resonances. The relation (5) assumes that Γ does not depend on E; this approximation is valid if the penetrability does not vary appreciably over the width of the resonance.

If the detected particle in a kinematically incomplete experiment does not belong to the resonant system $|T_{if}|_R^2$ can be brought outside the integral since it then depends only on the momentum of the particle detected at an angle θ. The residual integral reduces to the phase space factor R_{N-1} and the resonant part of the spectrum will be represented by the relation

$$\frac{d^2\sigma}{d\Omega_N dT_N} \propto \frac{p_N}{v_0} \frac{\Gamma^2/4}{(E-E_0)^2+\Gamma^2/4} \times R_{N-1}(m_1, \ldots, m_{N-1}; T^*, P^*) . \qquad (6)$$

In the present calculations we have restricted ourselves to three-body final states ($N=3$).

The experimental spectrum shape has been compared with the incoherent sum of nonresonant [phase space model relation (4)] and resonant parts [relation (6)].

A computer program was written to compare this sum, convoluted by the experimental resolution, to the observed spectra.

In the fitting procedure the free parameters were the strength coefficients C_i of the nonresonant parts, the strength coefficients $|T_{if}|_F^2$ for each level, and the width Γ and the energy E_0 of the resonances.

In order to fit the broad levels the peak corresponding to the 3.56 MeV level in ^{6}Li was introduced in the fitting procedure with a Gaussian shape equal to that of the ground state. The fit was made between 3 MeV excitation in ^{6}Li up to the ^{3}He-t breakup threshold ($E_{exc}=15.8$ MeV).

The starting point of the procedure was given by the published resonance parameters[4] and the strength coefficients obtained from a fit of that part of the spectra free of resonances.

IV. RESULTS AND DISCUSSION

A. 2.18 MeV (3^+,0) level

We have measured at all angles the position of the centroid of the peak corresponding to the 2.185 MeV level. We have neglected its width because it is much smaller ($\Gamma \sim 24$ keV) than the experimental resolution. The positions of the centroid (relative to

TABLE II. Parameters (Ref. 4) of the 4.3 MeV (2^+,0) level of ^{6}Li.

Reference	Channel	E_{exc} (MeV)	Γ (MeV)
7	$\alpha+d$	4.52±0.08	
11		4.87	
12		4.6 ±0.1	
13		4.28	1.34
14		4.7	
15	^{6}Li(p,p')	4.4 ±0.2	0.6
16	^{6}Li(p,p')	4.45	0.3
17	^{6}Li(e,e')	4.27±0.04	0.69±0.12
18	^{6}Li(d,d')	4.32±0.04	1.82±0.11
19	^{6}Li(p,px)	4.40±0.12	1.49±0.15
20	^{7}Li(τ,α)	4.3 ±0.2	
21	^{9}Be(p,α)	4.40±0.12	0.35±0.15
22	^{7}Li($\tau,\alpha d$)	4.3 ±0.1	0.6 ±0.1
Present work	^{9}Be(p,α) at $E_p=30$ MeV	4.29±0.02	0.85±0.05
	^{9}Be(p,α) at $E_p=50$ MeV	4.30±0.01	0.48±0.08

the ground state) obtained at all measured angles are shown in Fig. 1.

The mean excitation energy is

$$E_{\mathrm{exc}}=2.209\pm0.005 \text{ MeV at } E_p=30 \text{ MeV}$$

and

$$E_{\mathrm{exc}}=2.197\pm0.006 \text{ MeV at } E_p=50 \text{ MeV} .$$

A comparison with the published data indicates a large discrepancy. We will distinguish two sets of data: (a) measurements of α-d resonances, which yield a value of 2.185 ± 0.003 MeV (Ref. 7); and (b) reaction measurements which yield values ranging from 2.17 ± 0.02 MeV (Ref. 8) up to 2.194 MeV with no quoted uncertainty.[9] Most of the existing measurements do not report the precision on the energy. We are thus unable to make a clear statement on the coherence of the reaction measurements.

Our values for the excitation energy are higher than the accurate value obtained by Galonski *et al.*[7] obtained from α-d scattering. On the other hand the analysis of possible systematic errors does not explain such a deviation (12 to 24 keV) with our measurements. Our conclusion is that the shift is due to the observation of a two-body resonance via a nuclear reaction, namely, interferences of the third particle (here an alpha particle) with the observed two-body resonance (^{6}Li*, $E_x \cong 2.18$ MeV).

The evaluation of the interference effect would require at least three-body calculations with inclusion of Coulomb effects. An approximate treatment has been developed for other systems and the interferences have been found to be important.[10]

B. 4.3 MeV (2^+,0) level

The parameters of this level have been much disputed by both experimentalists and theoreticians. Similar and contradictory values exist especially for the width of this level. The existing data on the parameters of that level are presented in Table II. We have divided them into four parts. In the first one we present the data obtained by phase shift analysis of α-d scattering. In the second part we present the parameters obtained by inelastic scattering and quasifree scattering while in the third part we list the parameters obtained using various reaction channels.

One observes considerable disagreements for the width of this level. Two different values for the width seem to exist: a large one including the elastic scattering data and some of the inelastic scattering data, and a small one including part of the inelastic scattering data and all reaction data. Except for the works of von Witsch *et al.*[19] and Schwartz and Fou[22] the analysis of the data was done neglecting the contribution of the phase space factor to the shape of the peak as shown in Eq. (6) and taking for the nonresonant part of the spectrum an arbitrary background.

In our analysis the "background" component was supposed to be given by the phase space model predictions and we have assumed the 4.3 MeV level to be a pure α-d state. We should repeat here that the analysis was carried out simultaneously for the whole spectrum and the 3.56, 4.3, 5.37, and 5.65 MeV states. Typical fits to the spectra are shown in

TABLE III. Parameters (Ref. 4) of the 5.37 MeV (2^+,1) level of ^{6}Li.

Reference	Channel	E_{exc} (MeV)	Γ (MeV)
23	^{7}Li(d,t)	~5.4	~0.6
	^{6}Li(d,d)		
20	^{7}Li(τ,α)	5.29 ±0.05	
		5.35 ±0.07	<0.1
21	^{9}Be(p,α)	5.32 ±0.06	0.28 ±0.06
24	^{7}Li(τ,α)	5.47 ±0.04	~0.6
15	^{6}Li(p,p')	5.4 ±0.2	~1.0
16	^{6}Li(p,p')	5.28 ±0.08	0.30 ±0.05
8	^{7}Li(τ,α)	5.34 ±0.02	0.56 ±0.04
25	^{7}Li(τ,α)	5.36 ±0.03	0.54 ±0.04
17	^{6}Li(e,e')		0.44 ±0.10
19	^{6}Li(p,px)	5.33 ±0.08	$0.55^{+0.34}_{-0.10}$
Present	^{9}Be(p,α)		
work	at $E_p=30$ MeV	5.324±0.005	0.274±0.024
	^{9}Be(p,α)		
	at $E_p=50$ MeV	5.329±0.007	0.269±0.012

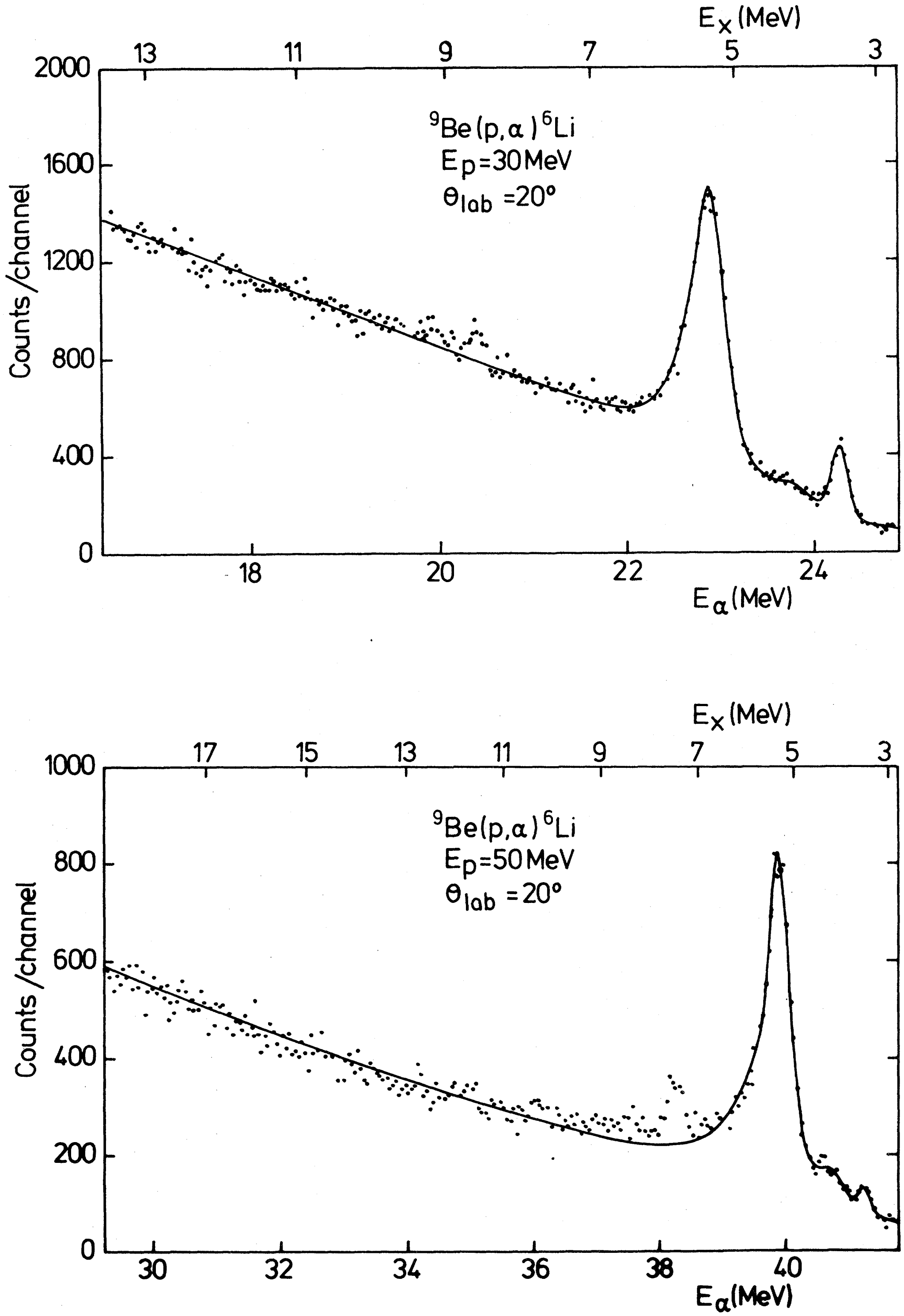

FIG. 2. Typical fits to the experimental spectra of the ^{9}Be(p,α) reaction. (a) Spectrum taken at $\theta=20°$ for $E_p=30$ MeV. The small peak seen around $E_x=9$ MeV is due to the (p,α) reaction on a carbon contamination. (b) Spectrum taken at $\theta=20°$ for $E_p=50$ MeV. The small peak seen around $E_x=7.5$ MeV is due to the (p,α) reaction on a carbon contamination.

Fig. 2. The mean values over the measured angular range are

$E_{exc}=4.29\pm0.02$ MeV ,

$\Gamma=0.85\pm0.05$ MeV at $E_p=30$ MeV ;

$E_{exc}=4.30\pm0.01$ MeV ,

$\Gamma=0.48\pm0.08$ MeV at $E_p=50$ MeV .

The excitation energies are compatible with each other except at angles smaller than 20°. The mean extracted widths belong to the category of small widths. The values are stable versus the detection angle but significantly different at 30 and 50 MeV. These discrepancies could have different origins: (a) a hereto unknown level in ^{6}Li contributing in the region of the 4.3 MeV level; (b) the p-α quasifree scattering contribution not being included in the calculation of the background since its contribution was shown to be small[6]—it may nevertheless play a role and influence the extracted parameters of the 4.3 MeV level; or (c) an interference mechanism of the kind reported above for the 2.18 MeV level.

A similar treatment starting with a reaction allowing only the feeding of $T=0$ states would be needed in order to obtain a more precise set of parameters for the broad 4.3 MeV level.

C. 5.37 MeV $(2^+,1)$ state

Previous data on this level are summarized in Table III.

As far as their excitation energy is concerned the overall agreement of the data is good except for the value of Linck *et al.*[24] The widths range from 0.28 to 0.6 MeV excluding the measurement of Allen *et al.*[20] due to contamination, and the value reported by Hasselgren *et al.*[15] because of the poor precision.

For all the measurements presented in Table III, the position and width were obtained as the centroid and the width of the experimental peak deconvoluted for the resolution after the subtraction of an arbitrary background.

The $(2^+,1)$ state does not decay in the α-d channel as was shown by von Witsh *et al.*,[19] its main mode of decay being the ^{5}He$+p$ channel. Another striking feature of the analyses performed so far is that only Allen *et al.*[20] have taken into account the possible contribution of the nearby $(1^+,0)$ state at ~5.65 MeV seen as a resonance in $\alpha+d$ scattering.

Following the results of von Witsch *et al.*[19] we have fitted the 5.37 MeV peak with a Breit-Wigner form multiplied by the α-^{5}He-p phase space. The fitting procedure was applied to all data except for the 25° and 30° data at $E_p=50$ MeV because of a contamination in the spectra by the ^{12}C(p,α) reaction.

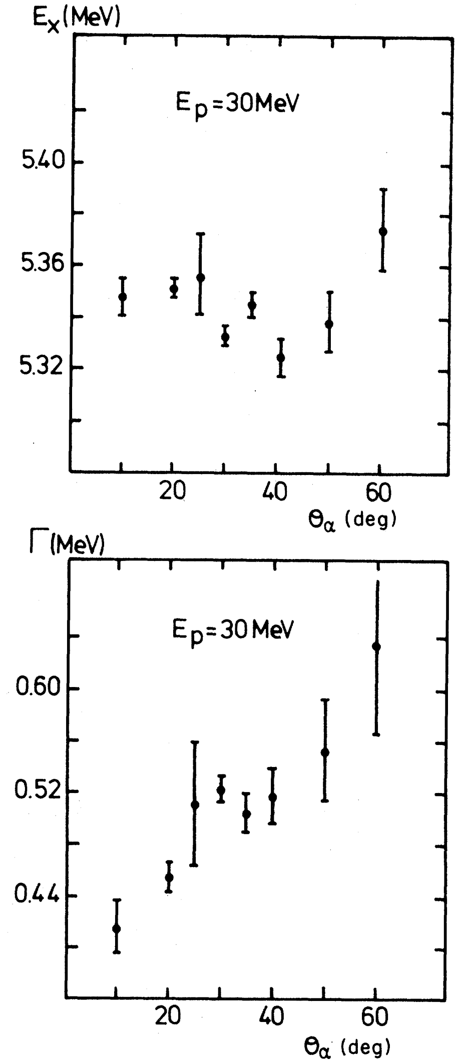

FIG. 3. Width of the 5.37 MeV $(2^+,1)$ level extracted from the measurement of the ^{9}Be(p,α) reaction disregarding the presence of the 5.65 MeV $(1^+,0)$ level.

In the first step of the analysis we did not introduce the contribution of the 5.65 MeV state. The deduced excitation energies (about 5.36 MeV) were constant versus the detection angle. The resulting widths are shown in Fig. 3 at $E_p=30$ MeV. The widths range from 0.42 to 0.64 MeV and cover almost the whole range given in Table III.

In a second step we included the contribution of the $(1^+,0)$ state at about 5.65 MeV excitation energy letting the exact position and width be determined by the fitting procedure. The results obtained with this more complete analysis are shown in Fig. 4. The inclusion of the $(1^+,0)$ state drastically improves the coherence of the parameters with angle. The mean values of the parameters are

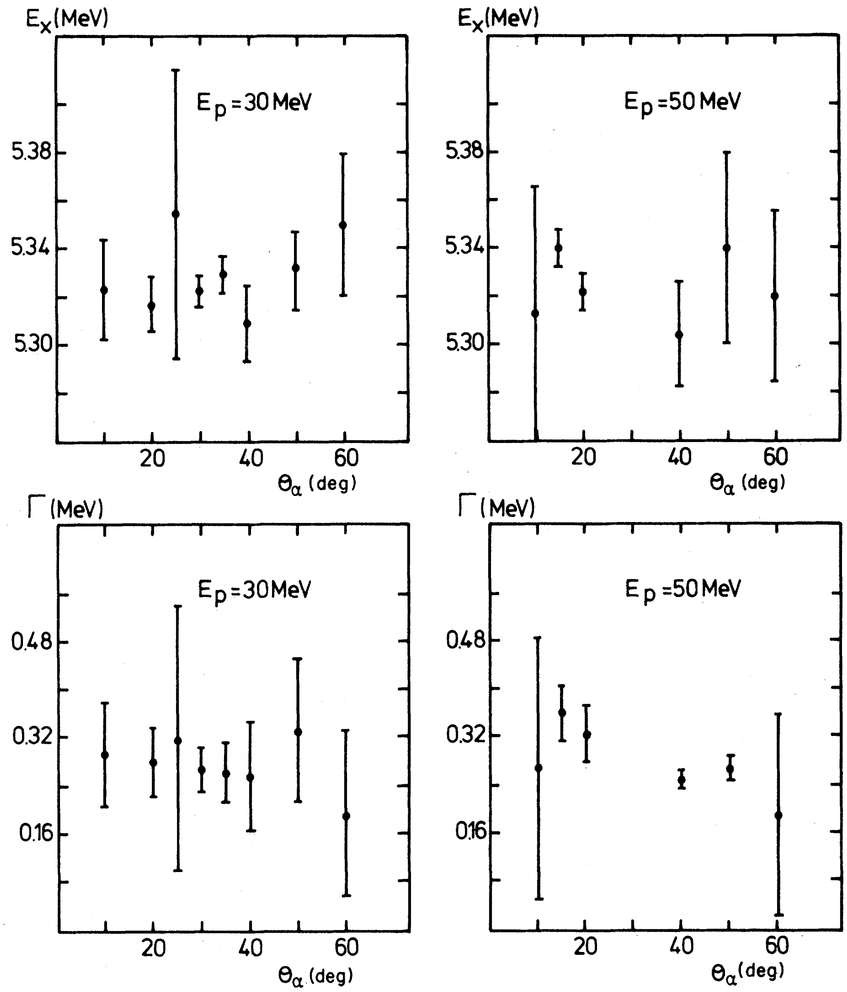

FIG. 4. Position and width of the 5.37 MeV $(2^+,1)$ level taking into account the contribution of the 5.65 MeV $(1^+,0)$ level.

$$E_{exc}=5.324\pm0.005 \text{ MeV} ,$$

$$\Gamma=0.274\pm0.024 \text{ MeV at } E_p=30 \text{ MeV} ;$$

$$E_{exc}=5.329\pm0.007 \text{ MeV} ,$$

$$\Gamma=0.269\pm0.012 \text{ MeV at } E_p=50 \text{ MeV} .$$

The position of the level is 40 keV lower than the energy accepted so far. The extracted value of the width is in agreement with the results of Groce and Whaling[21] and with those of Mani and Dix[16] but is much smaller than the mean value 540±20 keV quoted in Ref. 4 on the basis of Table III.

To be sure that our data are coherent with the data published in the literature we have applied to our spectra the usual practice used in the papers reported in Table III, namely, disregarding the existence of the nearby $(1^+,0)$ level and the effect of the phase space factor. The result of such an analysis has given

$$E_{exc}=5.368\pm0.006 \text{ MeV} ,$$

$$\Gamma=0.55\pm0.01 \text{ MeV} ,$$

in excellent agreement with the published mean values.[4]

We conclude therefore that the disagreement with the parameters we have extracted is really due to the way the analysis is performed and not to an artifact of the experiment.

In a further step we tested the effect of including an α-n-p structure for this level. This type of configuration assumes that the decay proceeds simultaneously and not sequentially. The extracted position was lowered by 16 keV and the width by 20 keV

TABLE IV. Parameters (Ref. 4) of the 5.65 MeV (1^+,0) level of the ^{6}Li nucleus.

Reference	Channel	E_{exc} (MeV)	Γ (MeV)
7	$\alpha+d$	4.9 −5.8	
11		6.24	
12		5.7 ±0.1	
13		5.01	2.7
14		5.7	
26		5.65	
20	^{7}Li(τ,α)	5.6 ±0.2	2.0
19	^{6}Li(p,px)	5.7 fixed	$1.0^{+0.6}_{-0.4}$
Present work	^{9}Be(p,α) at $E_p=30$ MeV	5.63±0.04	0.90±0.06
	^{9}Be(p,α) at $E_p=50$ MeV	5.68±0.04	1.26±0.12

compared to the results obtained by assuming a pure ^{5}He+p structure.

D. 5.65 MeV (1^+,0) level

The (1^+,0) level has been observed so far in relatively few cases, mainly by $\alpha+d$ scattering. The existing data are presented in Table IV. From the table it is visible that the parameters are very poorly determined. The presence of this resonance hardly appears to the naked eye in the spectra but rather is needed in the analysis to stabilize the level parameters of the (2^+,1) state, much in the same way that von Witsch *et al.*[19] needed the same state to fit the 4.3 MeV level in their data.

In the fitting procedure we have assumed an ($\alpha+d$) structure for the (1^+,0) state. The mean extracted values for the excitation energy and width are

$$E_{exc}=5.63\pm0.04 \text{ MeV} ,$$

$$\Gamma=0.90\pm0.06 \text{ MeV at } E_p=30 \text{ MeV} ;$$

$$E_{exc}=5.68\pm0.04 \text{ MeV} ,$$

$$\Gamma=1.26\pm0.12 \text{ MeV at } E_p=50 \text{ MeV} .$$

The extracted position is in good agreement with a recent phase shift analysis[26] and the width is in agreement with previous results.[19]

E. Other levels

In a recent paper[6] we mentioned that we have encountered a broad anomaly of relatively small amplitude in the region of excitation energy 8–12 MeV.

Owing to the fact that this anomaly is visible only at forward angles and that the statistics prevented a meaningful analysis we do not report on possible parameters although the parameters quoted earlier[27] seem to be a reasonable description of the observed anomaly.

We have also observed[6] anomalies in the region 18–24 MeV corresponding to known levels at ~21 and ~21.5 MeV,[4] but for the same reasons as above we did not attempt a detailed analysis.

V. CONCLUSION

The present analysis and the results published previously show that the phase space model allows for a precise determination of the nonresonant parts of the transition matrix and that it can be used in an efficient way to substract the so-called "background" under the peaks due to resonances in the continuum.

Representing the resonances by a Breit-Wigner form with a constant width and taking correctly into account the phase space factors of final state particles we have been able to extract the positions and widths of the low lying resonant levels in the ^{6}Li nucleus.

Our results show that a careful analysis of the data can reveal states not observable otherwise, as was the case for the (1^+,0) 5.65 MeV state, and can contribute to a better knowledge of the resonance parameters.

It is, however, necessary to point out that this type of analysis requires the knowledge of the level structure to extract the parameters of a state.

The implication of the results obtained is that whenever we are confronted with levels of substantial width relatively close to the end point of a particular breakup, the parameters extracted by simple treatment of the spectra will give erroneous results.

The present cases are not isolated exceptions and similar revisions should be made for many levels of light nuclei.

[1]B. Charnomodic, C. Fayard, and G. H. Lamot, Phys. Rev. C 15, 864 (1977).

[2]R. Ceuleneer, M. Erculisse, and M. Gilles, Phys. Lett. 65B, 101 (1976).

[3]H. H. Hackenbroich, P. Heiss, and Le-Chi-Niem, Nucl. Phys. A221, 461 (1974).

[4]F. Ajzenberg-Selove, Nucl. Phys. A320, 1 (1979), and references quoted therein.

[5]P. Guazzoni, I. Iori, S. Micheletti, N. Molho, M. Pignanelli, and G. Tagliaferri, Nuovo Cimento 67A, 407 (1970); G. Gambarini, I. Iori, S. Micheletti, N. Molho, M. Pignanelli, and G. Tagliaferri, Nucl. Phys. A126, 562 (1969); J. L. Perrenoud and R. M. Devries, Phys. Lett. 36B, 18 (1971); R. M. Devries, J. L. Perrenoud, I. Slaus, and J. W. Sunier, Nucl. Phys. A178, 424 (1972); R. M. Devries, J. W. Sunier, J. L. Perrenoud, M. Singh, G. Paić, and I. Slaus, *ibid.* A178, 417 (1972).

[6]Th. Delbar, Ph.D. thesis, University of Louvain, Louvain-la-Neuve, 1981 (unpublished); Th. Delbar, Gh. Grégoire, P. Belery, and G. Paić (unpublished).

[7]A. Galonski, R. A. Douglas, W. Haeberli, M. T. Ellistrem, and H. T. Richards, Phys. Rev. 98, 586 (1955); A. Galonski and M. T. Ellistrem, *ibid.* 98, 590 (1955).

[8]C. L. Cocke, Nucl. Phys. A110, 321 (1968).

[9]C. P. Browne and C. K. Bockelman, Phys. Rev. 105, 1301 (1957).

[10]W. Bretfeld, W. Burgmer, H. Eichmer, D. Gola, Ch. Heinrich, H. J. Helten, H. Kretzer, K. Prescher, and W. Schnorrenberg, Z. Phys. A 282, 365 (1977).

[11]L. S. Senhouse, Jr. and T. A. Tombrello, Nucl. Phys. 57, 624 (1964).

[12]L. C. Mc Intyre and W. Haeberli, Nucl. Phys. A91, 382 (1967).

[13]L. Kraus, I. Linck, and D. Magnac-Valette, Nucl. Phys. A136, 301 (1969).

[14]P. A. Schmelzbach, W. Grüebler, V. König, and P. Marmier, Nucl. Phys. A184, 193 (1972).

[15]D. Hasselgren, P. U. Renberg, O. Sundberg, and G. Tibell, Nucl. Phys. 69, 81 (1965).

[16]G. S. Mani and A. D. B. Dix, Nucl. Phys. A106, 251 (1968).

[17]F. Eigenbrod, Z. Phys. 228, 337 (1969).

[18]K. H. Bray, A. D. Frawley, T. H. Ophel, and P. B. Treacy, Aust. J. Phys. 28, 235 (1975).

[19]W. von Witsch, G. B. Mutcher, and D. Miljanic, Nucl. Phys. A248, 485 (1975).

[20]K. W. Allen, E. Almqvist, and C. B. Brigham, Proc. Phys. Soc. London 75, 913 (1960).

[21]D. E. Groce and W. Whaling, Phys. Rev. 132, 2614 (1963).

[22]H. Schwartz and C. M. Fou, J. Phys. G 1, L57 (1975).

[23]E. W. Hamburger and J. R. Cameron, Phys. Rev. 117, 781 (1960).

[24]J. Linck, I. Nicolas-Linck, R. Bilwes, and D. Magnac-Valette, J. Phys. (Paris) 24, 983 (1963).

[25]I. Linck, R. Bilwes, L. Kraus, R. Seltz, and D. Magnac-Valette, J. Phys. (Paris) 30, 17 (1969).

[26]R. A. Hardekopf, W. Grüebler, D. Jenny, V. König, R. Risler, H. R. Bürgi, and J. Nurzynski, Nucl. Phys. A287, 237 (1977).

[27]Th. Delbar, Gh. Grégoire, J. Lega, G. Paić, and P. Wastyn, Phys. Rev. C 14, 1659 (1976).