# Highly excited states in $^6$Li by the reaction $^9$Be$(p,\alpha)^6$Li

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The spectra from the reaction $^9$Be$(p,\alpha)^6$Li induced by 75 and 30 MeV protons were recorded at $\theta_\alpha = 20$ and 30° in the laboratory frame. The region from 6 to 18 MeV excitation energy of the residual nucleus was carefully studied for possible levels. Evidence for a $T = 1$ level at $E_x = 8.2 \pm 0.2$ MeV with a width $\Gamma = 2.2 \pm 0.2$ MeV is reported. No other levels were observed in the present spectra.

[NUCLEAR REACTIONS $^9$Be$(p,\alpha)$, $E$=30–75 MeV, measured $\sigma(E,\theta)$; phase-space analysis; deduced level in $^6$Li.]

Recently, several groups[1-3] have reported evidence for unbound states of $^6$Li in the region above 6 MeV and below 20 MeV excitation energy. The analysis of $d$-$\alpha$ scattering by Grüebler *et al.*[1] revealed evidence for a broad level between $E_d$(lab) = 11 and 15 MeV, corresponding to an excitation energy of about 10 MeV in the $^6$Li nucleus. Nocken *et al.*[2] observed broad maxima in the excitation function of the reaction $^3$H$(^3$He$, d)^4$He. They interpreted these maxima as possible levels in $^6$Li at 16.2 and 17 MeV excitation energy. Finally, Duisebaev *et al.*[3] reported the observation of a very narrow state ($\Gamma <$ 100 keV) at $E_x$ = 14 MeV in an investigation of the $^9$Be$(p,\alpha)^6$Li reaction. In order to investigate the possibility of detecting the states reported in Refs. 1 and 2 and to achieve a better characterization of the state reported in Ref. 3, we undertook an investigation of the $^9$Be$(p,\alpha)^6$Li reaction. Two measurements were performed at the variable energy cyclotron of Louvain-le-Neuve. The first was done with a 75 MeV analyzed proton beam, to achieve a large range of excitation in the residual nucleus. The $^4$He and $^3$He particles from the reactions $^9$Be$(p,\alpha)^6$Li and $^9$Be$(p,^3$He$)^7$Li, respectively, were detected by a $\Delta E$-$E$ telescope consisting of a 300 $\mu$m $\Delta E$-, a 3000 $\mu$m $E$-silicon detector, and a 1000 $\mu$m veto detector. To keep the broadening due to kinematics small we choose a solid angle of 0.057 msr. The overall full width at half maximum (FWHM) energy resolution achieved was 200 keV, the major part stemming from the target thickness. For the second measurement, we used a 30 MeV unanalyzed proton beam, and the telescope for $^3$He and $^4$He detection consisted of a 56 $\mu$m $\Delta E$-, a 1000 $\mu$m $E$-, and a 1000 $\mu$m veto detector. The overall resolution was 630 keV. For both measurements the target was a 12.5 $\mu$m thick self-supported beryllium foil. The particle identification was achieved with a Goulding type identifier unit. The $^3$He and $^4$He particles were detected simultaneously to ensure that features observed in the $\alpha$-particle spectra are not due to $^3$He leakage resulting from incomplete mass separation. Both $^3$He and $^4$He energy spectra were digitized with the same analog-to-digital converter and routed to distinct zones of 1024 channels in a PDP-8 computer. The $\alpha$-particle spectra obtained at $\theta_\alpha = 20°$, $E_p$ = 75 MeV, and $\theta_\alpha = 30°$, $E_p$ = 30 MeV are shown in Fig. 1. In order to search for possible broad structures in the continuum we compared the experimental spectra to the predictions

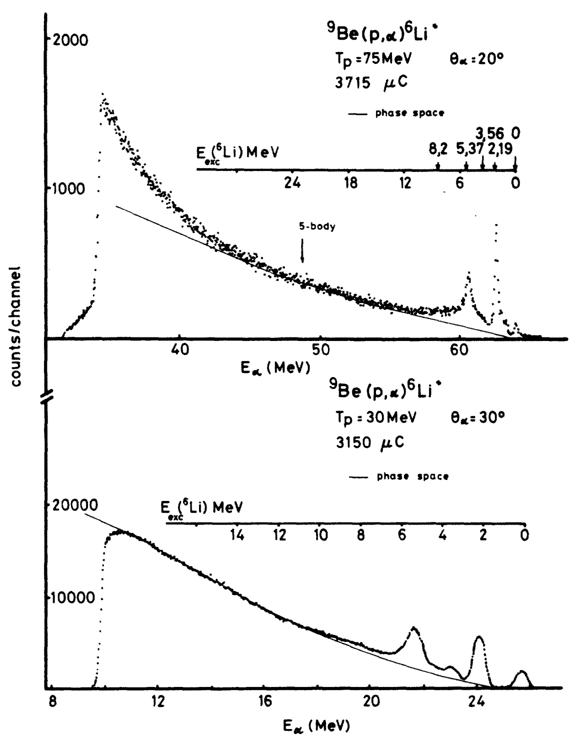


FIG. 1. (a) $\alpha$-particle spectrum from the reaction $^9$Be$(p,\alpha)^6$Li at 75 MeV. The detection angle is 20°. (b) $\alpha$-particle spectrum from the reaction $^9$Be$(p,\alpha)^6$Li at 30 MeV. The detection angle is 30°.

of a process assumed to be independent of the relative energy of the particles in the final state. The shape of the spectrum in this case is given by phase space considerations only. Since three- and four-body breakup may occur in the region studied, an incoherent sum of three- and four-body phase space contributions was compared to the data as shown in Fig. 1. From this comparison the following conclusions can be drawn.

(i) Within the sensitivity of the present experiment we did not find evidence for any broad level above 10 MeV. It is to be stressed that the very high contribution of energy independent interactions (phase space spectrum) prevents one seeing weakly excited states.

(ii) We have searched for the state reported in Ref. 3. We found no evidence to support the existence of this state observed in Ref. 3 with $d\sigma/d\Omega \simeq 200\ \mu b/sr$ at $E_p = 30$ MeV and $\theta_\alpha = 30°$. The upper limits of the cross section for the excitation of a narrow state in the region 12–16 MeV are 5.9 $\mu$b/sr and 0.27 $\mu$b/sr for the experiments at 30 and 75 MeV, respectively, taking a 95% confidence level. The occurrence of a narrow state in the 14–16 MeV region in $^6$Li might be connected with the search for $^3$He-$^3$He resonances to explain the lack of solar neutrinos. However, in experiments involving continuum spectra it is difficult to rule out completely the existence of such a level.[4]

(iii) There is a significant departure of the experimental spectra in the region $E_x = 6-10$ MeV. To explain the observed departure from the "phase space spectrum," we have considered possible parasitic contributions from the reactions $^9$Be($p$, $^5$He)$^5$Li, $^9$Be($p$, $^5$Li)$^5$He, $^9$Be($p$, $^6$Li*)$^4$He and $p$-$\alpha$ quasifree scattering on $^9$Be. From kinematical considerations all of these contributions can be ruled out. The remaining possibility is that the observed feature could be attributed to a level in $^6$Li. To find the position and width of such a level we subtracted the phase space contribution normalized to the excitation energy domain 10–18 MeV. This was done for the 30 MeV spectrum where we have the best statistics. The spectrum thus obtained was smoothed and two Breit-Wigner curves corresponding to the 5.37 MeV level and the unknown "level" were fitted. The contributions of the 5.7 and 4.3 MeV levels are seen to be small and therefore were not taken into consideration. The Breit-Wigner curves were multiplied by the four-body phase space factor before being compared to the results (Fig. 2). The fit yielded the following values for the new level $E_x = 8.2 \pm 0.2$ MeV, $\Gamma = 2.2 \pm 0.2$ MeV. The 75 MeV data taken at a different angle with lower statistics support these values. The 5.37 MeV level width extracted from the 30 MeV data was $\Gamma = 400 \pm 200$ keV, which

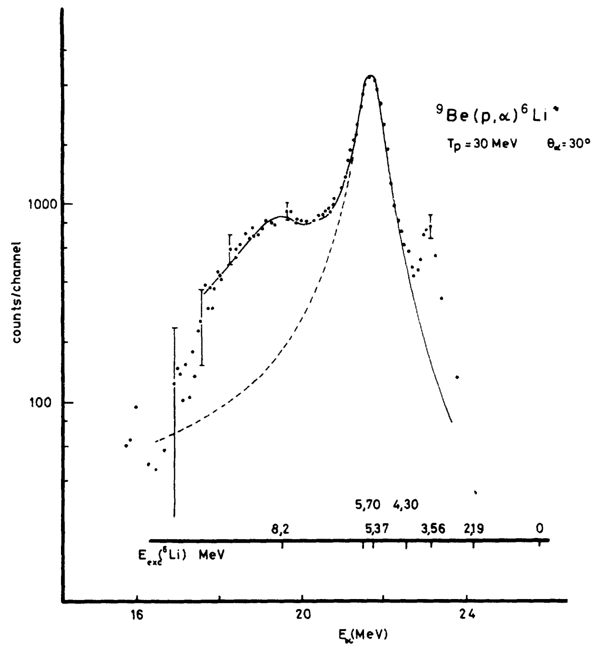


FIG. 2. Breit-Wigner fit and subtracted spectrum in the excitation energy range 3 to 10 MeV for the reaction $^9$Be($p$, $\alpha$)$^6$Li at 30 MeV. Every fourth channel is plotted.

is in reasonable agreement with the tabulated values.[5] This large uncertainty is due to our resolution at 30 MeV. The 5.37 MeV level width measured from the spectrum taken at 75 MeV is $600 \pm 50$ keV, in good agreement with the value quoted by Ajzenberg-Selove and Lauritsen.[5] The 4.3 MeV ($2^+$, 0) and the 5.7 MeV ($1^+$, 0) states may be interpreted[1,6] as a $^5$He($^5$Li) core in its ground and first excited state, respectively, coupled to a $p_{1/2}$ nucleon. Adopting the same reasoning, we consider the 8.2 MeV level to be of the form $[(A=5)^* + p_{1/2}]_{T=1}$ corresponding to the 5.37 MeV state of configuration $[(A=5) + p_{1/2}]_{T=1}$. Should the proposed level have an isospin $T = 1$, it should be a member of an isobaric triplet and should be visible in $^6$He and $^6$Be. Looking then at the spectra of the $^4$He($t$, $p$)$^6$He reaction[7] and at the spectra from the reaction $^6$Li($^3$He, $t$)$^6$Be,[8] one sees that as observed in the present experiment, a deformation occurs above the 1.80 MeV level in $^6$He and above the 1.67 MeV level in $^6$Be.

The absence of the comparison with a "phase space spectrum" and the restricted excitation range covered precluded in our opinion the earlier detection of the new level. On the basis of the experimental evidence it seems safe to assign it an isospin $T = 1$.

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