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The $^7Li(\alpha, t)\alpha\alpha$ and the $^6Li(\alpha, d)\alpha\alpha$ Reactions at 29.4 MeV

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Energy spectra of tritons from the $^7Li+\alpha$ reaction and of deuterons from the $^6Li+\alpha$ reaction were measured from 6° to 90° in the laboratory system. Anomalous broad peaks were observed in the energy spectra at forward angles. They cannot be ascribed to resonances in the residual nucleus ^8Be. It is suggested that these broad anomalous peaks are due to the sequential decay of the excited state of ^7Li and that of the excited state of ^6Li.

Angular distributions of tritons and deuterons from the reactions $^7Li(\alpha, t_0)^8Be_{g,nd}$, $^7Li(\alpha, t_1)^8Be_{1,st}$, $^6Li(\alpha, d_0)^8Be_{g,nd}$, and $^6Li(\alpha, d_1)^8Be_{1,st}$ were measured. These angular distributions were confirmed to be dependent on the spin of the residuals as noticed by Siemssen and Dehnhard.

I. INTRODUCTION

In a nuclear reaction with three or more particles in the final state, the energy spectrum of one of the final particles often has anomalous peaks. It has been suggested[1~6] that a peak which cannot be ascribed to a resonance in the residual nucleus, may occur by 1) the threshold effect,[1~4] 2) the compound potential effect,[5] and 3) the sequential decay effect.[6] In the energy spectra of the $^9Be(p, d)^8Be$ reaction, Beckner *et al.*[1] found the plateau at an excitation energy of about 1 MeV. Such an anomalous peak or ghost is expected for all reactions of this type in which a level, well separated from other levels of the same spin and parity, exists close to a threshold, from the form of the density of state function.[2] Some models[3,4] were proposed that an enchancement of the cross section for such reactions should be found close to any threshold. In order to explain the continuous spectra of alpha-particles coming from the reactions $^6Li+^6Li$, $^6Li+^7Li$ and $^6Li+^{10}B$, Garin *et al.*[5] proposed one-dimensional potential model in which the ^6Li makes with the target an activated complex decaying via the dissymmetric breakup. In the energy spectra of protons from the $^{12}C+d$ reaction, broad proton groups were observed[6] which cannot be explained by the excitation of residual nucleus ^{13}C, and Pitts *et al.*[6] showed that these broad peaks correspond to the two-body sequential decay $^{12}C+d \rightarrow ^{14}N^* \rightarrow ^{13}N^*+n \rightarrow ^{12}C+n+p$.

We have observed a broad triton peak in the $^7Li+\alpha$ reaction, and a broad deuteron peak in the $^6Li+\alpha$ reaction, which cannot be ascribed to a resonance in the residual nucleus ^8Be. The energy spectra of both particles (t and d) show strong angular dependence. In this paper the experimental results of the energy spectra are represented and analyzed with a simple PWBA calculation. From the analysis it is remarked that the angular distributions of tritons from the excited state of ^7Li and of deuterons from

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the excited state of ^6Li play an important role for the formation of the broad triton peak and of the broad deuteron peak, respectively.

The angular distributions of tritons leading to the ground and first excited states of ^8Be in the $^7Li+\alpha$ reaction and those of deuterons leading to the same states of ^8Be in the $^6Li+\alpha$ reaction had been measured at several incident energies.[8~11] From the results at 28.2 MeV incident energy,[11] it was remarked that the angular distributions show strong dependence on the final state spin of the residual nucleus. In the present

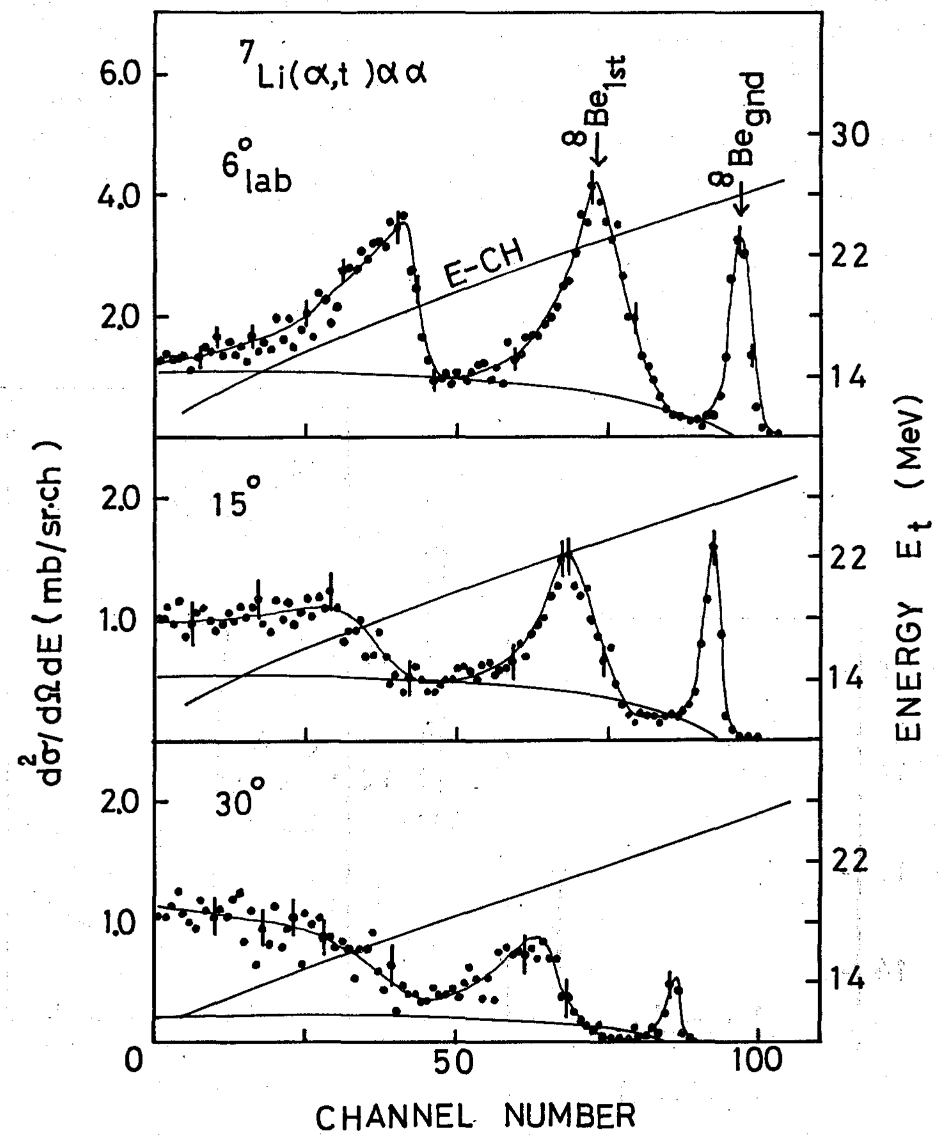

Fig. 1. Energy spectra of tritons at 6°, 15°, and 30° (lab) from the $^7Li+\alpha$ reaction with 29.4 MeV alpha-particles. Typical statistical error bars are shown. The curves labelled E–CH give the relation between particle energy and channel number. The smooth curves are the prediction of the phase psace factor.

experiment, in which the incident energy was 29.4 MeV, the angular distributions were also measured and found to have a very similar structure to those observed at 28.2 MeV.

II. EXPERIMENTAL PROCEDURES

A beam of 29.4 MeV alpha-particles from the Kyoto University cyclotron was used to bombard a self-supporting ^6Li (99.32%) or ^7Li (99.993%) target. The target thickness was 0.73 mg/cm^2 for ^6Li and 0.45 mg/cm^2 for ^7Li. Emergent particles were detected with a counter telescope consisting of 50 μm thick (ΔE) plus 1000 μm thick (E) solid state detectors of surface barrier type. The pulses from the two detectors (ΔE and E) were fed into a 32×128 two-dimensional pulse height analyzer (ND 160), and this procedure enables various particles to be distinguished. The energy resolution of tritons (deuterons) ranged from 400 KeV to 500 KeV (350 KeV to 500 KeV), depending on the particle energy. More detailed experimental procedures were as described previously.[7,13]

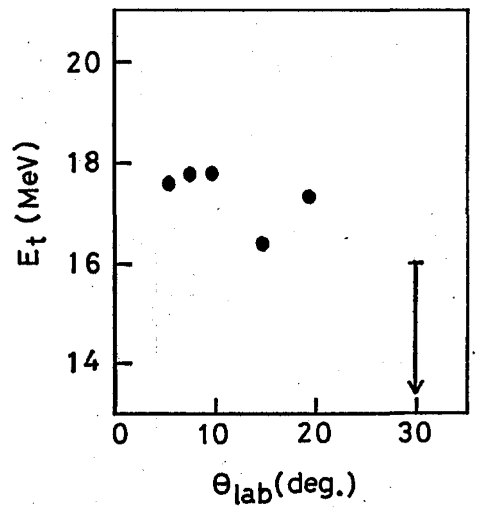

Fig. 2. Angular dependence of the triton energy corresponding to the maximum of the broad peak observed in $^7Li+\alpha$ reaction at 29.4 MeV.

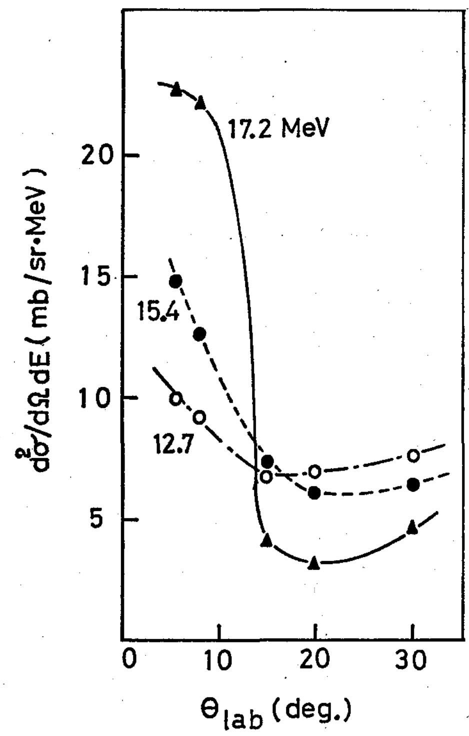

Fig. 3. The angular distributions of tritons ($d^2\sigma/d\Omega dE$) at the anomalous peak with energy of 17.2 MeV, 15.4 MeV and 12.7 MeV in the laboratory system.

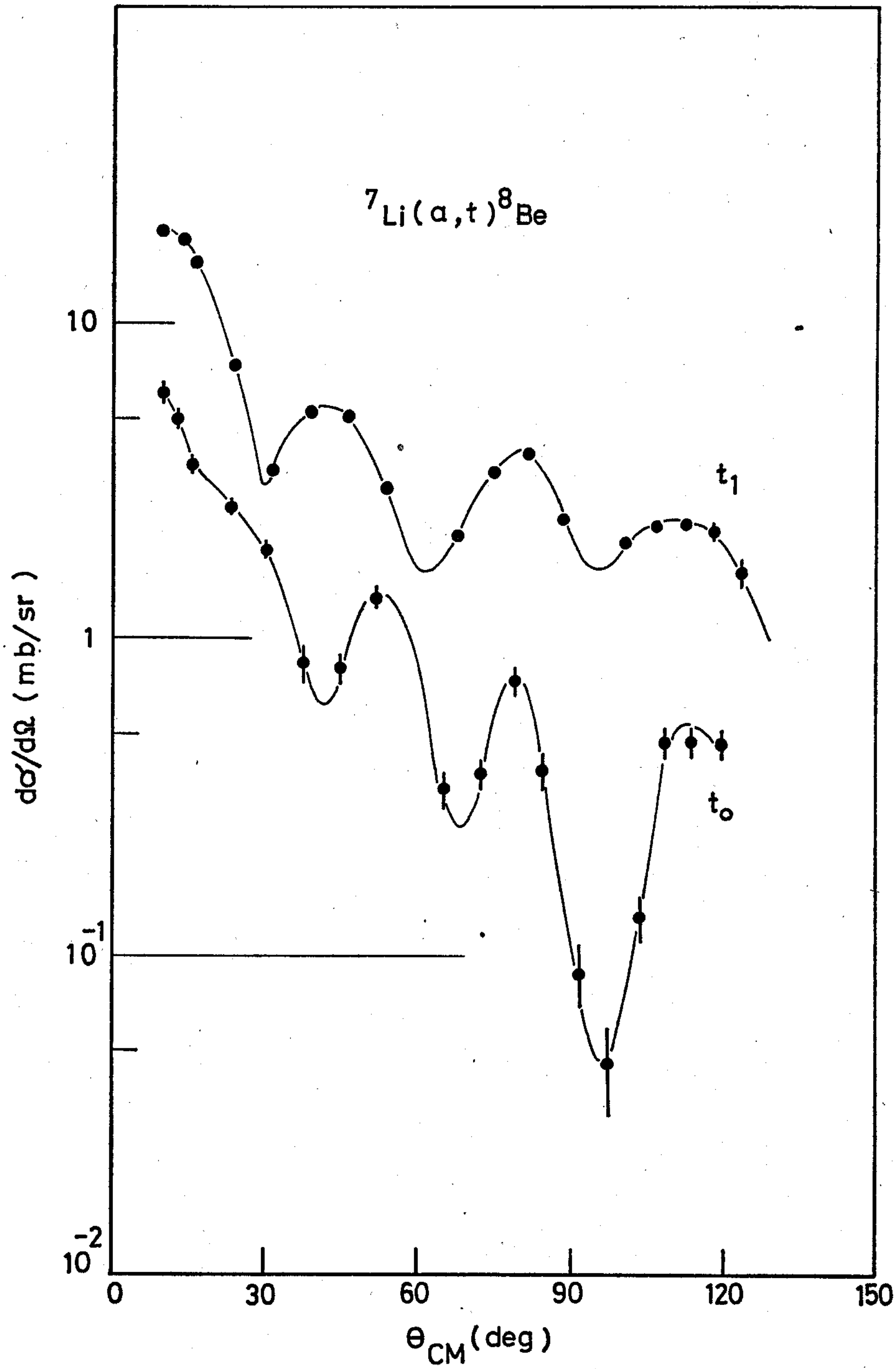

Fig. 4. The angular distributions of tritons from the reactions $^7Li(\alpha, t_0)\,^8Be_{g,nd}$ and $^7Li(\alpha, t_1)^8Be_{1,st}$ at 29.4 MeV.

III. RESULTS

III–1 ^{7}Li(α, t)$\alpha\alpha$ Reaction.

Energy spectra of tritons from the ^{7}Li$+\alpha$ reaction at 6°, 15°, and 30° in the laboratory system are shown in Fig. 1. Solid curves labelled E–CH in the figure show the relation between triton energy (E_t) and channel number. A broad triton group is observed around $E_t=18$ MeV, besides the two peaks corresponding to the ground state and the first excited state of ^{8}Be. The triton energy corresponding to the broad peak varies with detection angle as shown in Fig. 2. The width of the broad peak becomes larger as the scattering angle (θ_t) increases, and the peak disappears at angles larger than

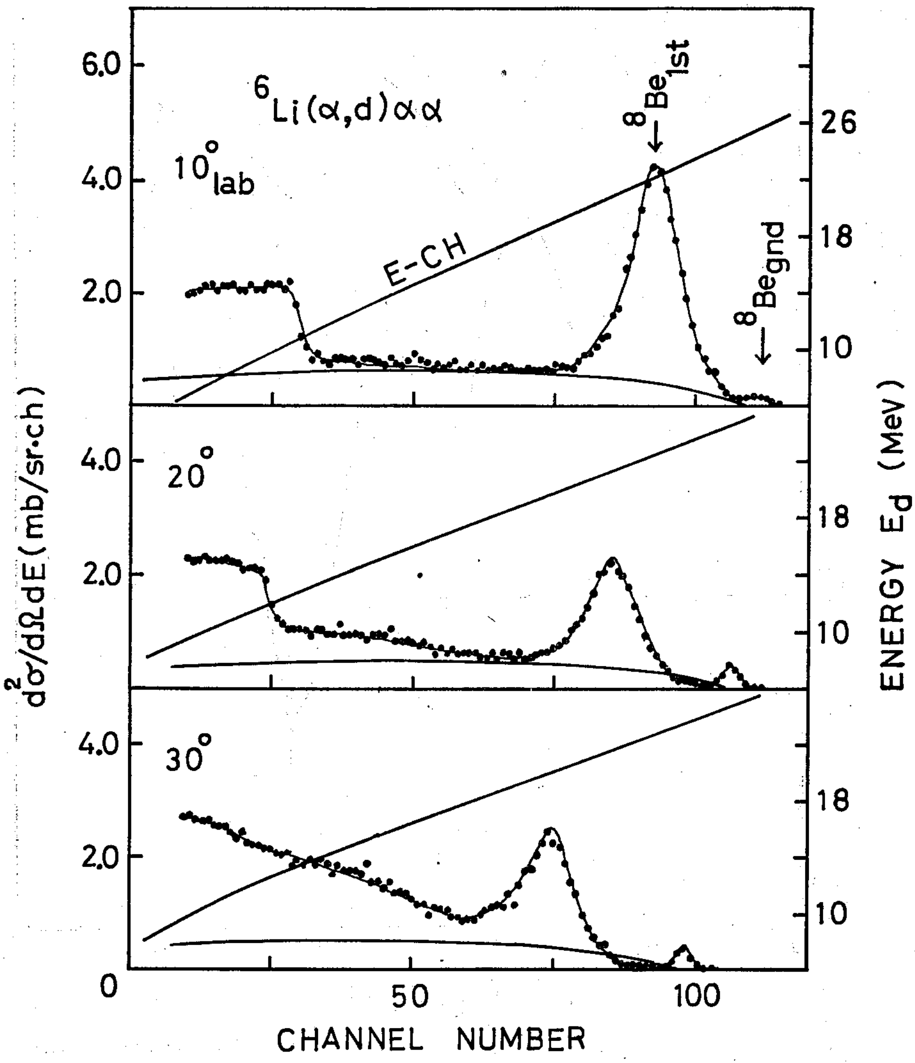

Fig. 5. Energy spectra of deuterons at 10°, 20°, and 30° (lab) from the ^{6}Li$+\alpha$ reaction with 29.4 MeV alpha-particles. See the caption for Fig. 1.

40°. The cross section of scattered tritons at the peak decreases rapidly at $\theta_t = 15°$ to 25° and then becomes constant at angles larger than 25° as shown in Fig. 3. In the figure are shown the angular dependence of the cross section of tritons ($d^2\sigma/d\Omega_t dE_t$) with energies of 17.2 MeV, 15.4 MeV, and 12.7 MeV in the laboratory system.

The angular distributions of tritons leading to the ground and first excited states of ^8Be are shown in Fig. 4. Background subtraction was made by assuming a smooth distribution under the peak.

III–2 $^6Li(\alpha, d)\alpha\alpha$ Reaction.

Energy spectra of deuterons from the $^6Li + \alpha$ reaction at 10°, 20°, and 30° in the laboratory system are shown in Fig. 5. Solid curves labelled E–CH in the figure show the relation between deuteron energy (E_d) and channel number. An anomalous peak was observed besides the two peaks corresponding to the ground and the first excited state of ^8Be. The deuteron energy corresponding to the broad peak varies with the detection angle as shown in Fig. 6. The yield at the peak has a maximum near $\theta_d = 10°$ as shown in Fig. 7. In Fig. 7 is shown also the cross section of the continuously distributed deuterons between the anomalous peak and the peak of the first excited state of ^8Be.

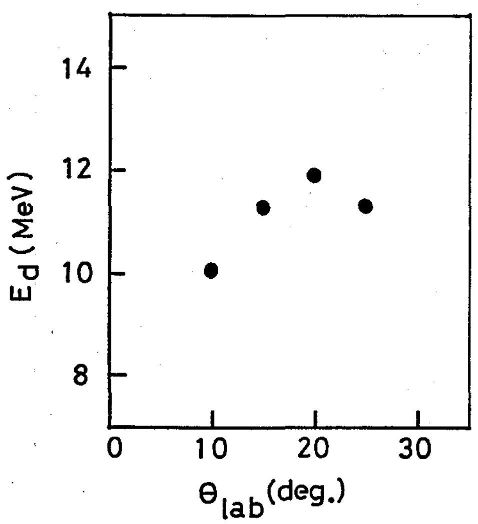

Fig. 6. Augular dependence of the deuteron energy corresponding to the maximum energy of the flat portion of the broad peak observed in the $^6Li + \alpha$ reaction at 29.4 MeV.

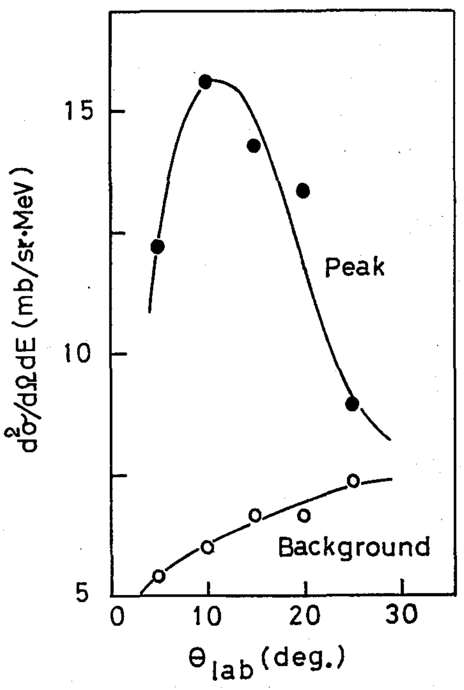

Fig. 7. The angular distribution of deuterons ($d^2\sigma/d\Omega dE$) at the plateau of the anomalous peak (labelled "Peak") and that of deuterons at the minimum between the first excited state of ^8Be and the anomalous peak (labelled "Background").

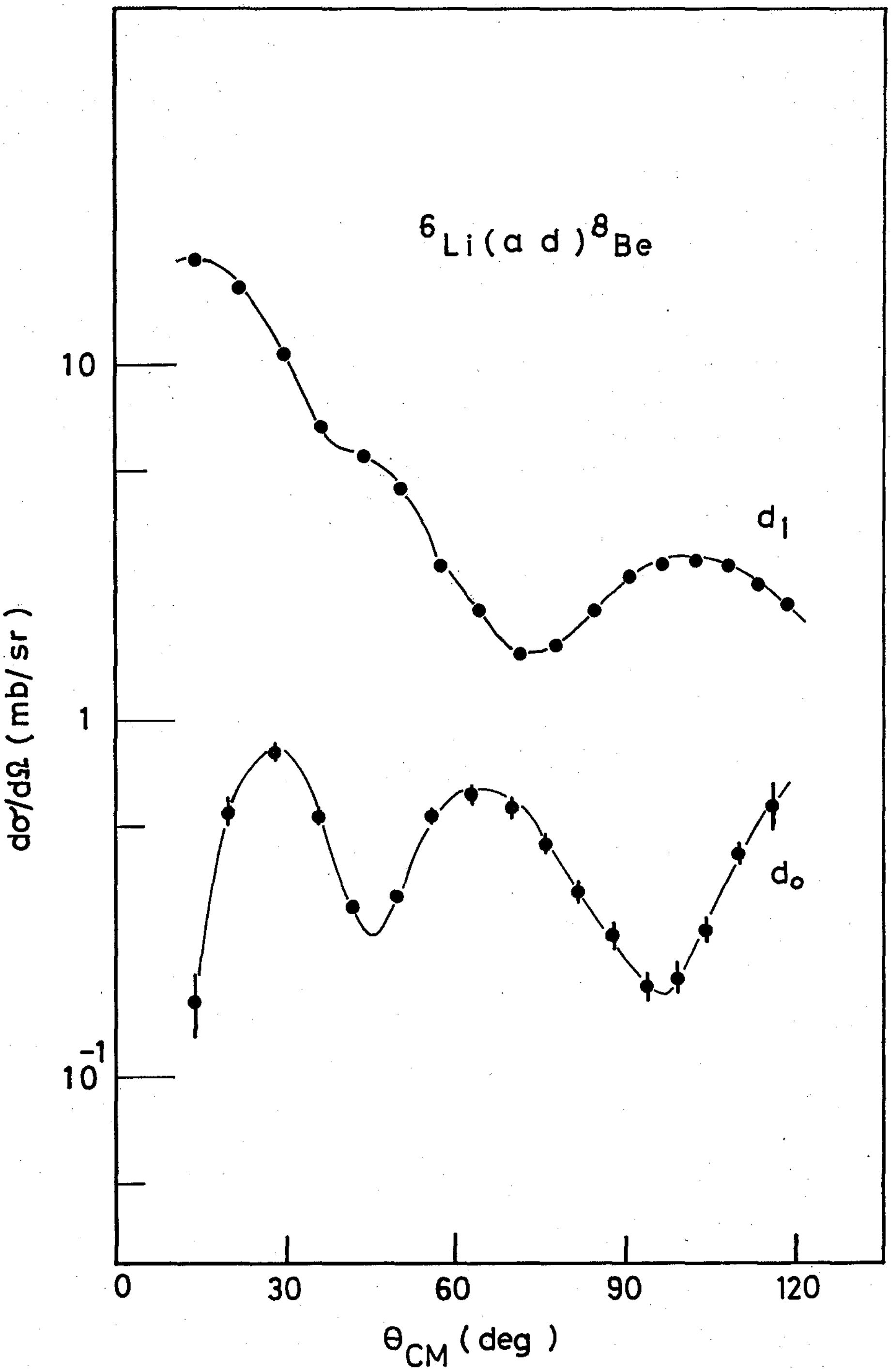

Fig. 8. The angular distributions of deuterons from the reactions $^6Li(\alpha, d_0)^8Be_{g,nd}$ and $^6Li(\alpha, d_1)$ $^8Be_{1,st}$ at 29.4 MeV.

The angular distributions of deuterons leading to the ground and the first excited states of ^8Be are shown in Fig. 8. Background subtraction procedure was the same as in the case of the $^7Li(\alpha, t)^8Be$ reaction.

The summed cross sections of tritons and deuterons from 0° to 90° in the center-of-mass system are tabulated in Table I.

Table I. The Summed Cross Sections (0°~90°) of Deuterons from the Reactions $^6Li(\alpha, d_0)^8Be_{g\cdot nd}$ and $^6Li(\alpha, d_1)^8Be_{1\cdot st}$, and of Tritons from the Reactions $^7Li(\alpha, t_0)^8Be_{g\cdot nd}$ and $^7Li(\alpha, t_1)^8Be_{1\cdot st}$.

	d_0	d_1	t_0	t_1
0°~90° (mb)	3.1	32	6.8	31

IV. ANALYSIS AND DISCUSSION

IV–1 Energy Spectra.

The broad peak observed in the energy spectra of tritons from the $^7Li+\alpha$ reaction cannot be attributed to any excited state of ^8Be. The particle identification was well performed as shown in a previous paper[13] and no similar anomalous peaks were observed in other particles (p, d or α groups) spectra. Contaminants in the target such as ^{16}O and ^{12}C do not contribute in this part of the energy spectrum, because of the high negative Q-values for the (α, t) reaction. The energy of the triton group corresponding to the excitation of the 4^+ state of ^8Be (11.4 MeV) is much lower than that of the observed triton group. Therefore, this anomalous broad peak must be due to a mechanism other than that leaving the residual two alpha-particles in the excited state of ^8Be.

The energy of the broad deuteron peak is near that corresponding to the excitation of the 4^+ state of ^8Be. The deuterons from the $^{12}C(\alpha, d)^{14}N$ and $^{16}O(\alpha, d)^{18}F$ reactions, due to the contaminants in the target, could also affect the shape of the peak. However, the deuteron energy corresponding to the anomalous peak increases with the detection angle θ_d as seen in Fig. 6. This behavior cannot be explained kinematically by considering the contributions of the 4^+ state of ^8Be, nor of the $^{12}C(\alpha, d)^{14}N$ and $^{16}O(\alpha, d)^{18}F$ reactions. Therefore, this anomalous broad peak must be due to a mechanism other than that leaving the residual two alpha-particles in the excited state of ^8Be.

These broad peaks cannot be accounted for with the phase space factor, as shown in Figs. 1 and 5. Furthermore, the threshold effect[1~4] cannot explain the spectrum shape, since no reaction thresholds have been found near this energy region.

In order to explain the continuous energy spectra of alpha particles in the $^6Li(^6Li, \alpha)\alpha\alpha$ reaction,[14] Garin *et al.* proposed a one-dimensional potential model.[5] This approach cannot be applied to the present case, because the model does not explain the angular dependence of the energy spectra.

In order to see the effect of a sequential decay process such as

$$^7Li+\alpha\rightarrow{}^7Li^*+\alpha\rightarrow\alpha+t+\alpha,$$

on the energy spectra of tritons, the kinematical relation of the triton energy (E_t) versus the inelastic scattering angle in the center-of-mass system (θ_α^{CM}) and versus the triton polar and azimuthal angles in the recoil center-of-mass system (θ_t^{RCM}, ϕ_t^{RCM}) were calculated. In a previous experiment,[13] the 4.63 MeV state of ^{7}Li was found to be preferentially excited in the inelastic scattering of alpha-particles. Therefore, it was assumed that the 4.63 MeV state of ^{7}Li was excited by the inelastic scattering and then decays into an alpha-particle and a triton. The velocity diagram and the co-ordinate system are shown in Fig. 9. Details of the kinematical relations will be reported elsewhere.

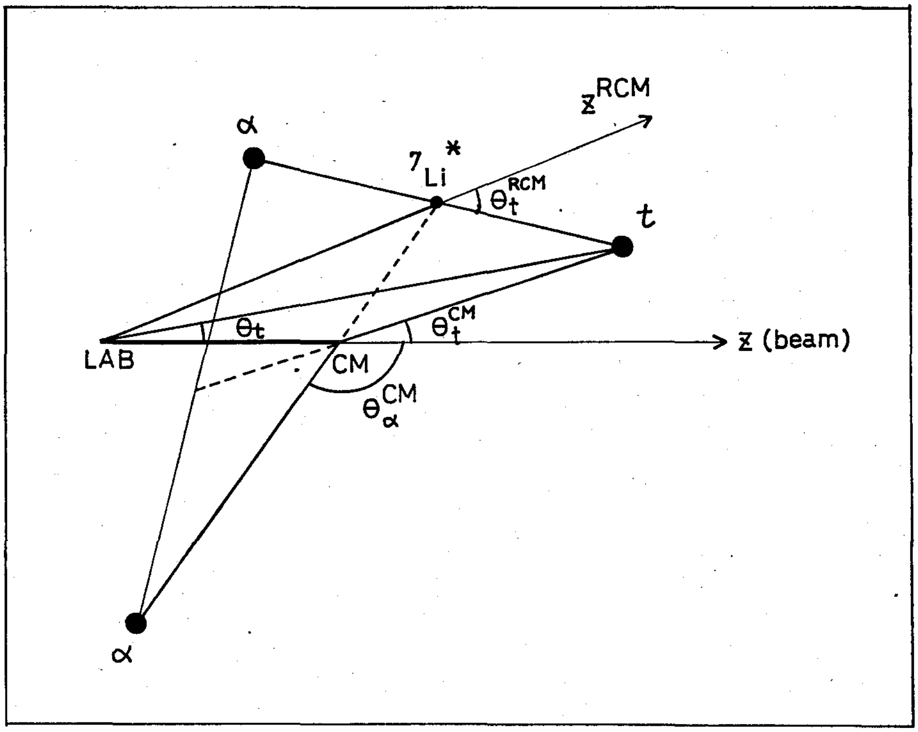

Fig. 9. The velocity diagram and the co-ordinate system in the $^7\text{Li}+\alpha\rightarrow\alpha+\alpha+t$ reaction.

The results of the calculated kinematical relations are shown in Fig. 10, where only the maxima and minima of θ_α^{CM} and θ_t^{RCM} are shown for E_t, and the possible allowed regions of ϕ_t^{RCM} are indicated in the figure. As seen from Figs. 1, 2, and 10, the observed anomalous peak begins to rise up at an excitation energy near the maximum possible energy of tritons which are from the excited state of ^{7}Li at 4.63 MeV. This fact strongly suggests the existence of the effect of the sequential decay on the anomalous peak observed.

The relative cross section for the production of tritons in the laboratory system was calculated from the assumed expression,

$$\frac{dN_t}{dE_t d\Omega_t}=A\int\frac{d\sigma(\theta_\alpha^{CM})}{d\Omega_\alpha^{CM}}\cdot f(\theta_t^{RCM},\ \phi_t^{RCM})\cdot J(\Omega_\alpha^{CM},\ \Omega_t)d\Omega_t^{RCM}$$

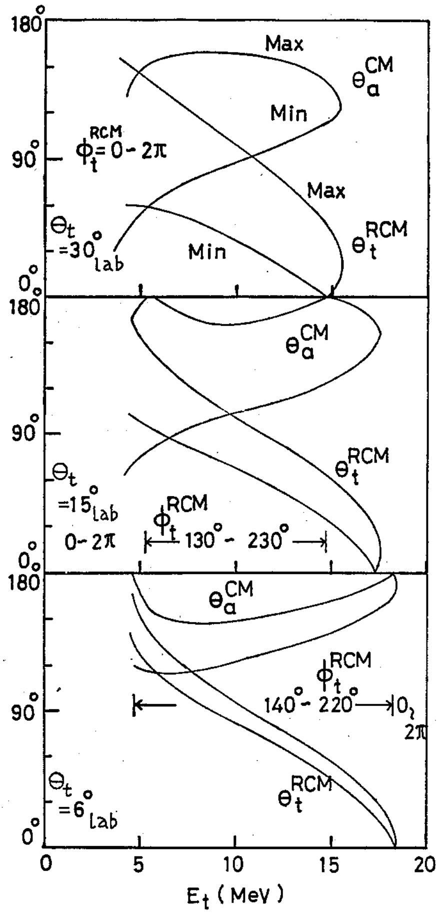

Fig. 10. The relation of the triton energy (E_t) versus the inelastic scattering angle of alpha-particles in the center-of-mass system (θ_α^{CM}) and versus the triton angle in the recoil center-of-mass system (θ_t^{RCM}, ϕ_t^{RCM}) in the sequential decay kinematics of the $^7\mathrm{Li}+\alpha\rightarrow{}^7\mathrm{Li}^*_{4.63}+\alpha\rightarrow\alpha+\alpha+t$ reaction. Only the maximum and the minimum of the corresponding θ_α^{CM}, θ_t^{RCM} and ϕ_t^{RCM} are shown.

where A is a constant, $d\sigma(\theta_\alpha^{CM})/d\Omega_\alpha^{CM}$ is the differential cross section of the inelastic scattering of alpha-particles from ^{7}Li leading to the excited state at 4.63 MeV, $f(\theta_t^{RCM}, \phi_t^{RCM})$ is the angular distribution of tritons from the break up of the excited state of ^{7}Li into $\alpha+t$ in the recoil center-of-mass system and $J(\Omega_\alpha^{CM}, \Omega_t)$ is the Jacobian for the transformation of the solid angle in the center-of-mass system for alpha-particle detection ($d\Omega_\alpha^{CM}$) into the solid angle in the laboratory system for triton detection ($d\Omega_t$),

$$J(\Omega_\alpha^{CM}, \Omega_t)=\frac{\sin\theta_\alpha^{CM}d\theta_\alpha^{CM}d\phi_\alpha^{CM}}{\sin\theta_t d\theta_t d\phi_t}$$

The integration about Ω_t^{RCM} is performed for all allowed solid angles resulting tritons with energy between E_t and $E_t+\Delta E_t$ in the solid angle $d\Omega_t$.

The angular distribution of alpha-particles from the 4.63 MeV excitation was found to be not oscillatory but rather flat.[13] Since the angular distribution at backward angles

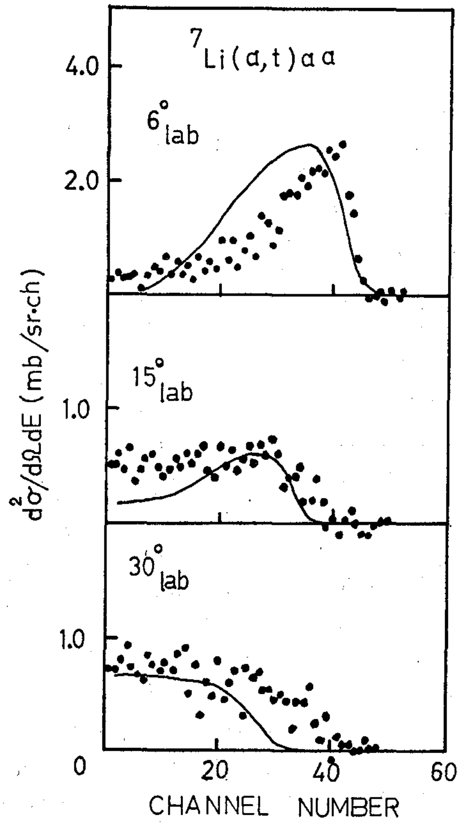

Fig. 11. The calculated energy spectra of tritons assuming a sequential decay, $^7Li+\alpha\rightarrow{}^7Li^*_{4.63}+\alpha\rightarrow\alpha+t+\alpha$, using a PWBA theory. The calculated results are normalized to the experimental spectra at the maximum of the anomalous broad peak. The experimental spectra were obtained by subtracting the smooth background under the anomalous peak.

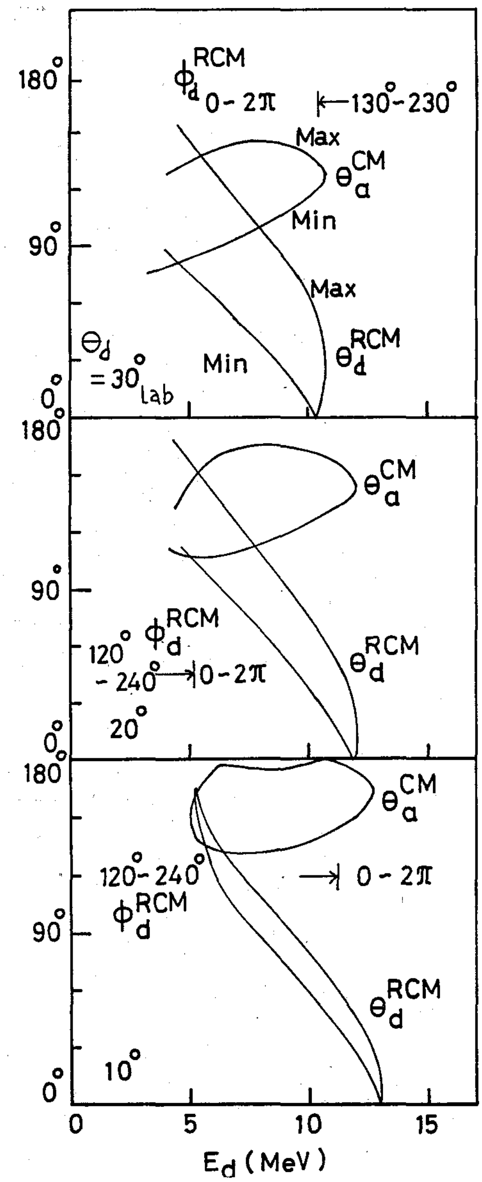

Fig. 12. The relation of the deuteron energy (E_d) versus the inelastic scattering angle of alpha-particles in the center-of-mass system (θ_α^{CM}) and versus the deuteron angle in the recoil center-of-mass system (θ_d^{RCM}, ϕ_d^{RCM}) in the sequential decay kinematics of the $^6Li+\alpha\rightarrow{}^6Li^*_{2.18}+\alpha\rightarrow\alpha+d+\alpha$ reaction. See the caption for Fig. 10.

were not measured, we assumed the flat distribution for all angles. The angular distribution of tritons from the break up of the excited state of ^{7}Li was calculated by a PWBA theory, in which the contribution of the orbital angular momenta to the polarization of the excited state of ^{7}Li (in the direction of the momentum of excited ^{7}Li nucleus in the laboratory system) is neglected and only the equally populated magnetic substates of $\pm 1/2$ and $\pm 3/2$ in the initial state of the target nucleus ^{7}Li were taken into account.[7,16] This assumption may be reasonable, since the angles of the inelastic scattering corresponding to the anomalous broad peak region are near 180° as shown in Fig. 10, and, therefore, the contribution of the orbital angular momentum to the polarization of the excited ^{7}Li nucleus is expected to be not so large. The orbital angular momentum between an alpha-particle and a triton in the excited ^{7}Li nucleus is assumed to be 3. (The spin-parity of the excited state is known to be $7/2^-$.)

The Jacobian $J(\Omega_\alpha^{CM}, \Omega_t)$ is approximately proportional to $d\Omega_\alpha^{CM}/d\Omega_t^{RCM}$ since the ratio $d\Omega_t^{RCM}/d\Omega_t$ is roughly constant for the present kinematical conditions. It was, then, assumed that the $J(\Omega_\alpha^{CM}, \Omega_t)$ is not dependent on the variable Ω_t^{RCM} and proportional to the ratio of the allowed solid angles $\Delta\Omega_\alpha^{CM}/\Delta\Omega_t^{RCM}$ resulting tritons with energy between E_t and $E_t+\Delta E_t$ in the solid angle $\Delta\Omega_t$.

The calculated results are shown in Fig. 11, in which the calculated spectra were normalized at the maximum of the experimental spectra. In spite of the rather crude approximation, the calculations reproduce the experimental energy spectra well in its characteristic features. It is especially to be noted that the angular dependence of the

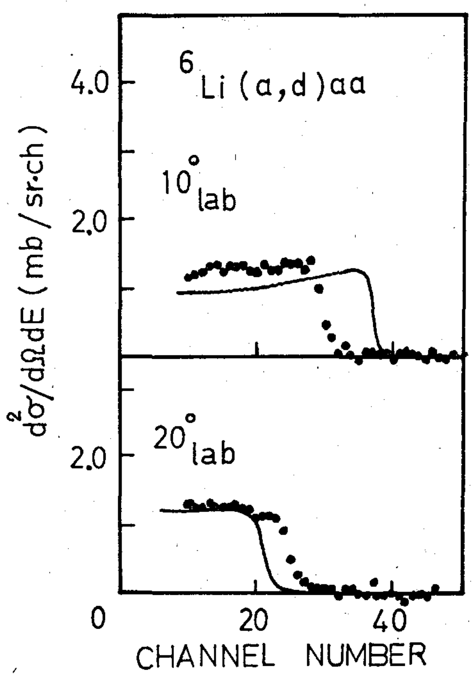

Fig. 13. The calculated energy spectra of deuterons assuming a sequential decay, $^{6}Li+\alpha\rightarrow{}^{6}Li^{*}_{2.18}+\alpha\rightarrow\alpha+d+\alpha$ using a PWBA theory. See the caption for Fig. 11.

calculated energy spectra are consistent with the experiments. This angular dependence is mainly due to the effect of the anisotropic angular distribution of tritons from the breakup of the excited state of ^{7}Li into $\alpha+t$.

The same discussion applies to the deuteron spectrum from the ^{6}Li$+\alpha$ reaction. Similar kinematical relations as in the case of the ^{7}Li$+\alpha$ reaction, are shown in Fig. 12 for the ^{6}Li$+\alpha$ reaction, where it is assumed that ^{6}Li is excited in the 2.18 MeV state and then decays into an alpha-particle and a deuteron. As in the case of the ^{7}Li$+\alpha$ reaction, the anomalous peak begins to rise up at an energy near the maximum possible energy of deuterons, which are from the excited state of ^{6}Li at 2.18 MeV. The 2.18 MeV state of ^{6}Li is preferentially excited by inelastic scattering of 29.4 MeV alpha-particles.[13]

The energy spectra of deuterons were calculated using a PWBA theory in which deuterons are from the breakup of the excited state of ^{6}Li at 2.18 MeV with a relative angular momentum of 2.[7,16] (The spin-parity of this excited state is known to be 3^{+}.) The calculated results are shown in Fig. 13. The spectral shape is fairly well reproduced by the calculation, although the maximum energy, at which the anomalous peak begins to rise up, somewhat deviates from the experimental one.

The detailed comparison with the calculated spectra with the experimental results should be postponed. However, it is probably justified from the discussion presented above to state that the observed anomalous peaks are due to the effect of the sequential decay of the excited state of ^{7}Li and of ^{6}Li.

IV–2 Angular Distributions.

The measured angular distributions of tritons leading to the ground (t_0) and the first (t_1) excited states of ^{8}Be in the ^{7}Li$+\alpha$ reaction, and those of deuterons leading to the ground (d_0) and the first (d_1) excited states of ^{8}Be in the ^{6}Li$+\alpha$ reaction, have very similar structure to those measured at 28 MeV incident energy.[11] The angular distributions of the ground state transitions show a strong oscillatory pattern, while this structure is smeared out in the transitions to the first excited state. The ground state angular distributions are almost out-of-phase to those of the first excited state transitions.

Similar differences between the angular distributions leading to the ground state and excited states have been observed for other reactions on the very light ($A<12$) nuclei.[15] From the experimental results, Siemssen and Dehnhard[12] remarked the existence of the residual-state-spin dependence of the angular distributions. As suggested by them, one of the possible ways to explain this spin dependence of the angular distributions, may be to take account of the configuration mixing (f-admixture) of the ^{8}Be state. The $l=3$ admixture cannot be present in the transition to the ground state (spin zero) because of the angular momentum conservation. The stripping angular distribution leading to the ground state of ^{8}Be has been calculated in the distorted-wave Born approximation before trying to take account of the configuration mixing for the ^{7}Li(α, t_1)^{8}Be$_{1,st}$ reaction.

DWBA calculation was performed using DWBA–2 code.[17] The optical potential parameters used for alpha-particles are those obtained in the automatic search analysis of elastic scattering of alpha-particles by ^{7}Li[10], and those for tritons were chosen from

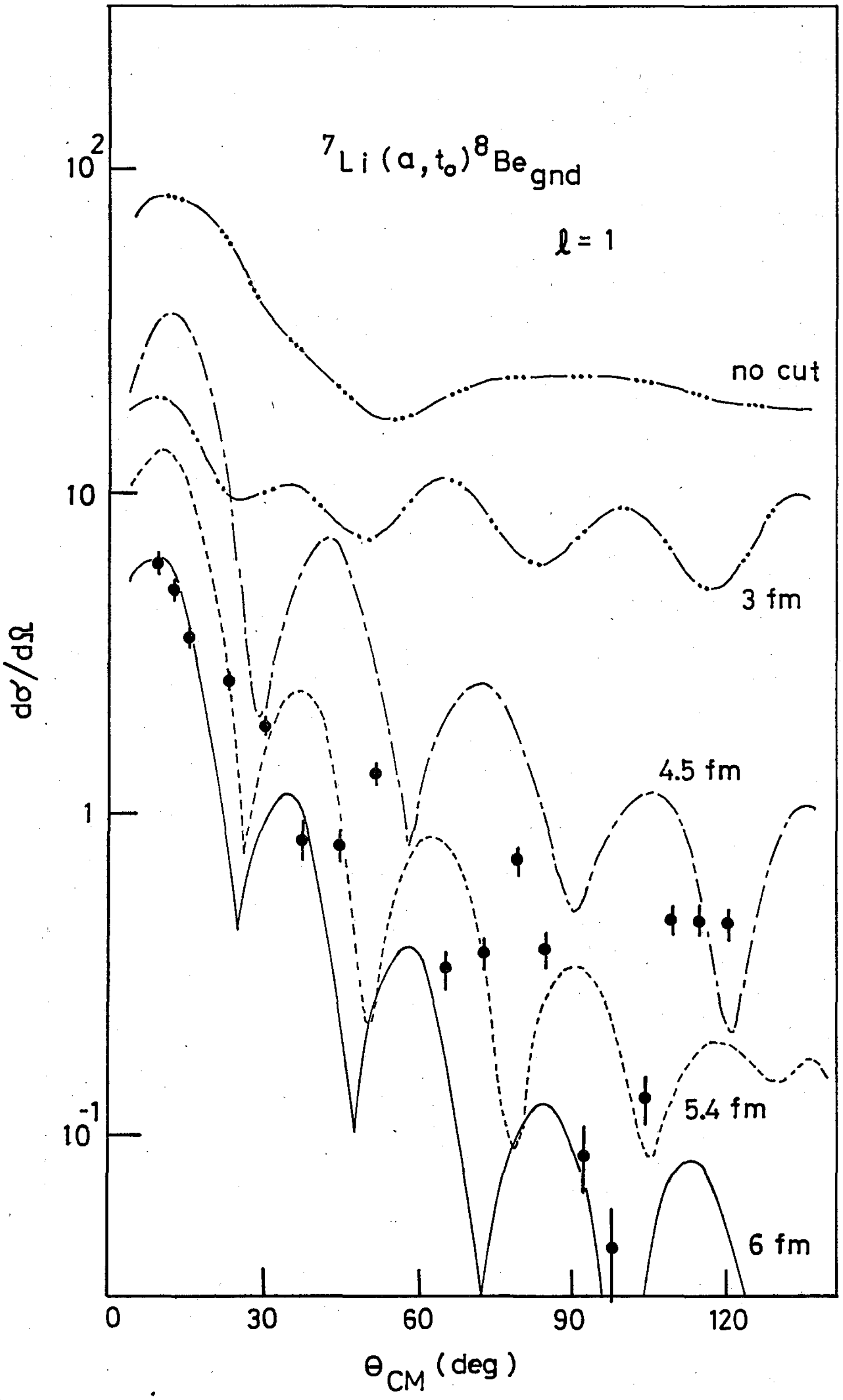

Fig. 14. Calculated angular distributions of the ^{7}Li $(\alpha, t_0)^8$Be$_{g,nd}$ reaction using a DWBA theory. The experimental angular distribution is also shown (Solid circles).

the extrapolation from other analysis in the $1-p$ shell nuclei.[18] Parameters of these potentials are listed in Table II. The bound-state form factor for the proton transferred to the state in ^{7}Li was taken to be the wave function of a proton in a Woods-Saxon potential, with a binding energy equal to the separation energy of a proton from ^{8}Be. The optical potential parameters for the transferred proton are also listed in Table II. The calculated results are shown in Fig. 14. As seen in the figure, the calculated angular distribution varies appreciably with the cut-off parameters, and the agreement between the calculated and the experimental results is not so good as to justify further calculations for the ^{7}Li(α, t_1)^{8}Be$_{1,st}$ reaction.

Table II. The Optical Model Parameters Used in the DWBA Calculations. Energies Are in MeV and Lengths in fm.

	V	W_{vol}	V_{so}	a_V ($=a_W$)	r_V	r_W	r_C
$\alpha+^7$Li	68.2	19.8		0.657	1.62	1.17	1.30
$t+^8$Be	58.0	14.0	4.0	0.80	1.40	1.40	1.30
Bound proton			4.0	0.65	1.25		1.25

In conclusion it is suggested that the anomalous peaks, observed in the energy spectra of tritons from the ^{7}Li$+\alpha$ reaction and of deuterons from the ^{6}Li$+\alpha$ reaction, are due to the sequential decay process in which the target nucleus are excited and then decays into two particles. It seems to be particularly important to take into account the decay angular distribution of particles from the excited state for understanding the energy spectra and its angular dependence. This point has not been relatively taken into consideration in other studies.[19]

The spin-dependent angular distributions of tritons and deuterons from the reactions ^{7}Li(α, t_0)^{8}Be$_{g,nd}$, ^{7}Li(α, t_1)^{8}Be$_{1,st}$, ^{6}Li(α, d_0)^{8}Be$_{g,nd}$, and ^{6}Li(α, d_1)^{8}Be$_{1,st}$ were observed at 29.4 MeV in the present experiment. A DWBA calculation assuming stripping mechanism for the ^{7}Li(α, t_0)^{8}Be$_{g,nd}$ reaction cannot reproduce well the observed angular distribution.

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REFERENCES

(1) E. H. Beckner, C. M. Jones, and G. C. Phillips, *Phys. Rev.*, **123**, 255 (1961).
(2) F. C. Barker and P. B. Treacy, *Nucl. Phys.*, **38**, 33 (1962).
(3) A. I. Baz, *Advances in Phys.*, **8**, 349 (1959).
(4) D. R. Inglis, *Nucl. Phys.*, **30**, 1 (1962).
(5) A. Garin, C. Lemeille, D. Maneses, L. Marquez, N. Saunier, and J. L. Quebert, *J.*

Phys., **25**, 768 (1964).

(6) A. E. Pitts, J. D. Bronson, T. A. Belote, and G. C. Phillips, *Nucl. Phys.*, **48**, 75 (1963).

(7) S. Matsuki, *J. Phys. Soc. Japan*, **24**, 1203 (1968)

(8) J. Cerney, B. G. Harvey, and R. J. Pehl, *Nucl. Phys.*, **29**, 120, (1962); J. Cerney, Ph. D. Thesis submitted to University of California, *UCRL* 9714 (1961).

(9) G. Deconninck and G. Demortier, *Phys. Lett.*, **7**, 260 (1963).

(10) K. V. Makaryunas and S. V. Starodubsev, *JETP*, **11**, 271 (1960); A. Vlasov, S. P. Kalinin, A. A. Ogloblin, and V. I. Chuev, *JETP*, **12**, 1020 (1961).

(11) H. E. Wegner, W. S. Hall, and D. W. Miller, *in Conference on Direct Interactions and Nuclear Reaction Mechanisms, Padua, Italy, 1962, edited by E. Clemental and C. Villi* (Gordon Breach, Publishers, New York, 1963), p. 1004.

(12) R. H. Siemssen and D. Dehnhard, *Phys. Rev. Lett.*, **19**, 377 (1967).

(13) S. Matsuki, S. Yamashita, K. Fukunaga, D. C. Nguyen, N. Fujiwara, and T. Yanabu, *J. Phys. Soc. Japan*, **26**, 1344 (1969).

(14) M. Kamegai, *Phys. Rev.*, **131**, 1701 (1963); E. H. Berkowitz, *Nucl. Phys.*, **82**, 52 (1966), and references there in.

(15) H. E. Wegner and W. S. Hall, *Phys. Rev.*, **119**, 720 (1960); R. J. Slobodrian, *Phys. Rev.*, **126**, 1059 (1962); K. P. Artemov, V. Z. Goldberg, B. I. Islamov, and V. P. Rudakov, *Soviet J. Nucl. Phys.* **1**, 726 (1965); D. Dehnhard and R. H. Siemssen, *Bull. Amer. Phys. Soc.*, **12**, 17 (1967).

(16) S. Yamashita, S. Matsuki, K. Fukunaga, D. C. Nguyen, N. Fujiwara, and T. Yanabu, *Contribution of International Conference on Nuclear Structure* (Tokyo, 1967) p. 253.

(17) M. Kawai, K. Kubo, and H. Yamaura, *INS-Report*, RT–9.

(18) P. E. Hodgson, *Optical Model Analyses of the Elastic Scattering of Helium-Three and Tritons by Nuclei*, private communication.

(19) Ref. 3) and V. Valkovic, I. Slaus, P. Tomas, and M. Cerineo, *Nucl. Phys.*, **A98**, 305 (1967).