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Continuum Spectra of Alpha Particles Scattered from ^{6}Li by Alpha Particles

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Continuum spectra of the scattered alpha particle for the ^{6}Li breakup reaction by an alpha particle at the incident energy of 119 MeV were measured. These spectra were fitted by using the 3, 4 and 5 body phase space calculation. Angular distributions of the deduced cross sections for each breakup channel were compared with those for the elastic scattering.

KEY WORDS: Nuclear reactions ^{6}Li(α, α)/ E=119 MeV/ Measured continuum energy spectra/ Compared with phase space calculations/ Enriched ^{6}Li target

1. INTRODUCTION

The ^{6}Li nucleus has the typical cluster structure, which is studied by many experimental and theoretical workers.[1] According to them, its ground state is consisted of $\alpha+d$ (70%) and $\alpha+N+N$ (30%). Almost of these experiments were done by detecting the scattered two particles. Generally in the correlation research, the fine structure of the nuclear reaction mechanism and the nuclear inner structure will be obtained. However, this measurement is restricted to the small part of all phase space. So the inclusive measurement is better for studying the gross structure of the breakup reaction of ^{6}Li. However there are no previous experiments which were done about the continuum spectra in detail. Therefore we detected the scattered alpha particle from the ^{6}Li breakup reaction and studied about the continuum energy spectra. To estimate what kind of breakup reactions is dominant, the phase space fitting are done.

2. EXPERIMENTAL PROCEDURE

An alpha particle beam accelerated by the AVF cyclotron at Research Center for Nuclear Physics (RCNP) of Osaka University bombarded a ^{6}Li (95.4% enrichment) target. The target thickness was 6.6 mg/cm^2 and the energy at the target center was 118.7 MeV. Scattered alpha particles were detected by the counter telescope consisted of 100 μm ΔE and 5 mm E Si solid state detectors. The other telescope consisted of 150 μm ΔE and NaI(Tl) E was used for the forward angle (20° and 34.4°) measurements. Measured angles are 20°, 30°, 34.4°, 40°, 44.4° and 50°. The E, ΔE signals were transmitted through a raw data processor to a PDP 11 computer. The offline analyses were done with the computers FACOM M-380 at RCNP, FACOM M-360R

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The overall energy uncertainty of the present experiment was about 1 MeV for Si SSD and about 2 MeV for NaI(Tl) and only statistical uncertainties of the cross section values were considered.

3. PHASE SPACE FITTING

If we suppose no particular reaction mechanisms occur, the continuum energy spectra will be explained by folding the phase space for each breakup reaction. Differential cross sections by the phase space calculation in the laboratory system is written as follows.[2)]

$$\frac{d\sigma}{d\Omega dE}=\Sigma A_j f_j$$

$$f_j=T_j^{\frac{1}{2}}(E_{tot}-T_j)^{\frac{3}{2}n-4}$$

Where T_j is the energy of the detected particle for the j-th breakup process in the center of mass system. E_{tot} is the total energy in the center of mass system. n shows the n-body breakup process. A_j is a normalization coefficient for the j-th breakup process, which we search by fitting. In the present study, the following breakup reactions were considered in fitting the energy spectra.

$$
\begin{aligned}
{}^6\mathrm{Li}+\alpha &\rightarrow \alpha+\alpha+d\\
&\rightarrow \alpha+\alpha+p+n\\
&\rightarrow \alpha+\tau+t\\
&\rightarrow \alpha+\tau+d+n,\ \alpha+t+d+p,\ \alpha+d+d+d\\
&\rightarrow \alpha+\tau+p+n+n,\ \alpha+t+p+p+n,\ \alpha+d+d+p+n
\end{aligned}
$$

About the 4 and 5 body breakup reactions except for the $\alpha+\alpha+p+n$, the results of three kinds of phase space calculation are not so different with each other because the mass of each particle is resemble. Therefore, in order to reduce the number of the fitting parameters, the $\alpha+\tau+d+n$ reaction is adopted for the 4 body breakup and the $\alpha+\tau+p+n+n$ for the 5 body breakup reaction.

4. RESULTS AND ANALYSES

Continuum spectra of the alpha particle scattered from ^{6}Li at 20°, 30°, 34.4°, 40°, 44.4° and 50° are shown in Fig. 1. Three peaks in the high energy region correspond to the g'nd (1^+), 1st (2.19 MeV, 3^+) and 3rd (4.31 MeV, 2^+) states of ^{6}Li. In case of 20° and 34.4°, these peaks were not separated because of the less energy resolution of NaI (Tl) counter. Arrows labeled 1 show the $\alpha+d$ breakup threshold energy and the $\alpha+p+n$ breakup threshold energy is 2.2 MeV lower than this. Arrows 2 show the $\tau+t$ breakup threshold energy, and the $\tau+d+n$ and the $t+d+p$ breakup reaction begins 5.5 MeV lower than this. In the lower energy region than the point of arrow 3, the 4 body breakup channels open. As the angle increases, yields in the low energy region grow up rapidly. This suggests that multi-particle breakup processes will easily occur in the backward region, where a large momentum transfers from the projectile to the target. Curves in the figure show the results of the phase space calculations. Curves fit to the energy

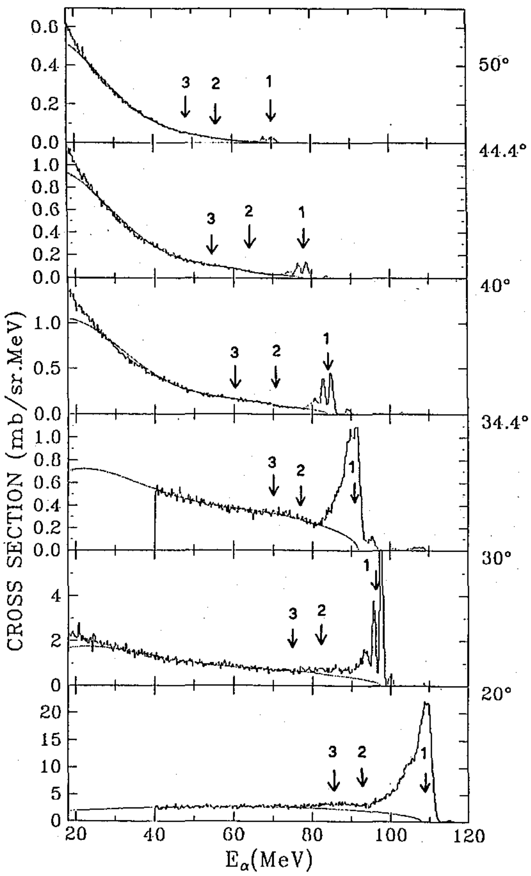

Fig. 1. Continuum spectra of the alpha particle scattered from ^{6}Li at 20°, 30°, 34.4°, 40°, 44.4° and 50°. Arrows labeled 1 show the $\alpha+d$ breakup threshold energy and arrows 2 the $\tau+t$. In the lower energy region than the point of arrows 3, the 4 body breakup channels open. Curves in the figure show the results of the phase space calculations.

Table 1. Breakup cross sections (mb/sr)

Reaction	20°	30°	34.4°	40°	44.4°	50°
$\alpha+\alpha+d$	225±32	47.6 ±15.2	24.4 ±0.6	7.00±0.10	2.77±0.32	0.505±0.648
$\alpha+\tau+t$	0.0	8.37±0.26	1.64±0.16	3.11±0.05	2.27±0.18	0.245±0.133
$\alpha+\alpha+p+n$	0.0	2.47±1.48	1.32±0.17	2.66±0.02	4.18±0.32	4.43 ±0.15
4-body	0.0	0.666±0.46	0.240±0.004	2.96±0.16	2.33±0.20	3.81 ±0.10
5-body	0.0	36.2 ±0.3	12.4 ±1.0	21.7 ±0.3	17.9 ±0.2	6.30 ±0.12

spectra well except for very low energy region, where more than 6 body breakup processes are necessary. In the forward angles (20° and 30°), there are some bumps deviated from the fitted curve in the high energy region. There are explained by the QFS processes where the alpha particle scatters quasi-freely from α or d in ^{6}Li. Except for them, no particular reaction mechanisms are seen in these spectra. Differential cross sections for each breakup channel obtained by this fitting are listed in Table 1. At 20°, the energy spectrum is reproduced with

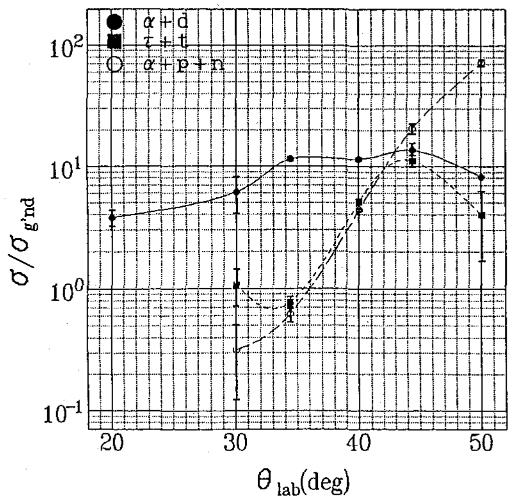

Fig. 2. The angular dependence of the cross section ratio for the $\alpha+d$, the $\tau+t$ and the $\alpha+p+n$ to the elastic scattering. Solid circles show the $\alpha+d$, solid squares $\tau+t$ and open circles $\alpha+p+n$.

only the $\alpha+\alpha+d$ reaction. As the angle increases, the differential cross section of this channel decreases. Compared to this channel, the $\alpha+\tau+t$ is not so necessary in the forward angular region. It corresponds to the status which α and d are loosely bound in the ^{6}Li ground state. However at large angles, both reactions are comparable with each other. It seems both structures of $\alpha+d$ and $\tau+t$ coexist in inner nuclei. The 4 body breakup channel grows up as the angle increases. It is reasonable considering the momentum transfer increases. However the 5 body breakup channel is always necessary except for 20°. Perhaps it contains the alpha knockout process. In this case, the ejected α from ^{6}Li by many body breakup process can be detected at forward angles.

Figure 2 shows the angular dependence of the cross section ratio for the $\alpha+d$, the $\tau+t$ and the $\alpha+p+n$ to the elastic scattering. Solid circles show the $\alpha+d$, solid squares $\tau+t$ and open circles $\alpha+p+n$. As seen in the ratio of the $\alpha+d$ channel is approximately constant. It means the angular dependences of the elastic scattering and the $\alpha+d$ breakup reaction are resemble. It seems that the inner motion of α and d in ^{6}Li does not have the angular momentum. It is explained that α and d is bound in S state of ^{6}Li. For the $\tau+t$ and $\alpha+p+n$, the results suggest that the inner motion has some angular momentum.

In summary, continuum spectra of α from ^{6}Li breakup reaction were almost reproduced by the phase space calculation. In the ordinary works, the spectra by the phase space is treated as the background because it shows no particular reaciton mechanisms. However, in this study, it could be one of the useful tools to study the breakup reaction. But to make a more detail discussion, it will be necessary to measure the angular distributions till larger angular region than this.

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REFERENCES

(1) For example, A. Okihana, T. Konishi, R.E. Warner, D. Francis, M. Fujiwara, N. Matsuoka, M. Tosaki, K. Fukunaga, S. Kakigi, T. Hayashi, J. Kasagi, N. Koori and M. Greenfield, *Nucl. Phys*, **A549**, 1 (1992).
(2) G.G. Ohlsen, *Nucl. Inst. Meth.*, **37**, 240 (1965).