Inclusive α and d in ^{6}Li+^{112}Sn system

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Introduction

The phenomenon of break-up of weakly bound light nuclei into $\alpha + x$ clusters in the field of a target nucleus is well established [1]. It has been observed that the production of α in a reaction is much higher compared to that of valence cluster x[2]. In an exclusive breakup reaction, $a + A \rightarrow (b + x) + A$, the state of the three outgoing fragments (b , x and A) is fully determined. But when one or more fragments is not specified,the reaction is said to be inclusive with respect to the unobserved particle(s). Experimentally it is very challenging to disentangle different reaction channels responsible for total inclusive breakup yield. The present work aims at measuring inclusive α and d particles produced in ^{6}Li+^{112}Sn reaction and disentangling different reaction channels responsible for their large cross sections by coupled-channels calculations to understand the underlying reaction mechanism.

The experiment

Measurements were carried out at five different energies: 22, 24, 26, 28 and 30 MeV, using BARC-TIFR Pelletron facility at Mumbai. Self-supporting ^{112}Sn foil of thickness$\sim$540 μg/cm^2 was used as target. Four Si-strip detector telescopes of active area 5 x 5 cm^2 (thicknesses ΔE$\sim$50 μm, E$\sim$1500 μm) with angular coverage 16.5° along with five telescopes ($\Delta E-E$) of Si-surface barrier detectors (of thicknesses ΔE$\sim$50 μm, E$\sim$1000 μm) with 5 mm collimator diameter each, were used to detect the projectile-like-fragments. Two Si-surface barrier detectors (of thicknesses$\sim$1000 μm) kept at $\pm$20° were used to monitor incident flux by measuring the Rutherford scattering.

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Analysis and discussion

The raw spectra of alpha and deuteron detected in any telescope show peaks around two-third and one-third of beam energies respectively. This implies that the above particles are mainly produced by projectile breakup mechanisms. Yields under these peaks were used to obtain the angular distribution of inclusive breakup-α and inclusive breakup-d for five different energies (22, 24, 26, 28 and 30 MeV) as shown in Fig. 1 and Fig. 2 respectively. The measured angular distribution data were first fitted with arbitrary functions by χ^2 minimization as shown by lines in the figures. The fitted curves were used to obtain the angle integrated cross-sections which are compared with the total reaction cross-section obtained from the fitting of elastic data using FRESCO. It shows that inclusive breakup α is one of the major reaction channels at near and above the coulomb barrier. So it would be highly interesting to estimate the α contribution from all possible channels in order to understand the origin of such a large inclusive-α for the present system.

In this work, it was identified that the major channels producing α particles due to non-capture breakup are (i) direct and resonant break-up of ^{6}Li $\rightarrow \alpha + d$ (ii) $1n$ stripping (^{6}Li,^{5}Li) followed by break-up i.e., ^{5}Li $\rightarrow \alpha+p$ (iii) $1d$ pickup (^{6}Li,^{8}Be) followed by break-up i.e., ^{8}Be $\rightarrow \alpha + \alpha$ (iv) $1p$ stripping (^{6}Li,^{5}He) followed by break-up i.e.,^{5}He $\rightarrow \alpha + n$. Ex-

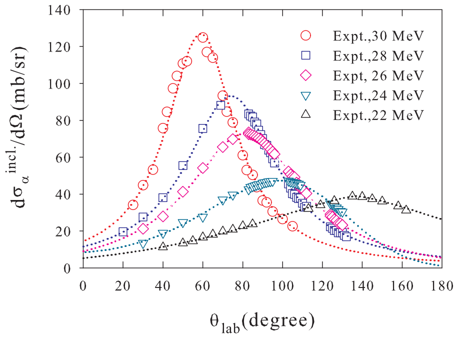

FIG. 1: Inclusive-α angular distribution for ^{6}Li+^{112}Sn at energies E_{lab} = 22−30 MeV. The dotted lines are fit to the experimental data.

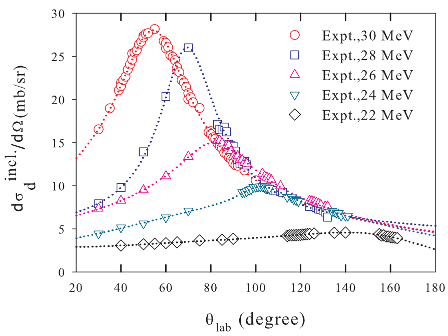

FIG. 2: Same as Fig.1 but for inclusive-d.

clusive breakup cross sections for first three channels at 22 and 30 MeV have been measured in the same experiment (not shown here) are consistent with the present calculations. Theoretical estimate for the fourth channel shows significant cross section but not measured due to lack of neutron detection. A list of angle integrated cross-sections for the above non-capture break-up channels obtained from the continuum discretized coupled channels (CDCC) and coupled reaction channels (CRC) calculations using FRESCO are compared with the measured inclusive data in Table 1. In CDCC calculations the binding potentials, maximum excitation energies in continuum and couplings related to the projectile are taken to be same as in Ref. [1].

For CRC calculations, the entrance channel potential is taken to be same as the optical model potential that fit the measured elastic scattering data and the spectroscopic factors are taken from the literature. Combined CC calculated cross sections found to constitute about 16-20% of experimental σ_{α}^{incl}.

One of the other major sources of inclusive-α could be due to breakup of ^{6}Li $\rightarrow \alpha + d$ followed by d-capture (incomplete fusion) and its contribution could be up to 50% of σ_{α}^{incl} as observed in case of ^{6}Li+^{209}Bi reaction [1, 2]. Additionally, the fusion-evaporation contribution to total α yield is found to be $\sim 7-8\%$ from statistical model calculations using the code PACE.

Comparing the measured data for inclusive-d with $\alpha + d$ cross sections in Table 1, it may be concluded that there are other channels like breakup followed by α capture by ^{112}Sn, etc. contributing to inclusive-d.

TABLE I: Calculated cross-sections for various channels producing α at E_{beam} = 22−30 MeV

E (MeV)	σ_{reac}^{th} (mb)	σ_{α}^{incl} (mb)	σ_{d}^{incl} (mb)	$\sigma_{\alpha+d}^{th}$ (mb)	$\sigma_{\alpha+p}^{th}$ (mb)	$\sigma_{\alpha+\alpha}^{th}$ (mb)	$\sigma_{\alpha+n}^{th}$ (mb)
30.0	1344	592 ±35	178 ±12	60.5	19.2	4.79	31.2
28.0	1175	584 ±32	156 ±11	55.9	17.65	4.77	26.0
26.0	978	527 ±28	126 ±9	47.8	15.96	4.72	20.75
24.0	698	392 ±21	89 ±6	34.4	13.88	4.49	15.52
22.0	493	309 ±16	46.5 ±4	24.5	10.32	3.43	10.45

Thus, present work providing a comprehensive list of exclusive cross sections obtained from theory as described above unravels many underlying reaction mechanisms producing large inclusive α and d particles that are measured.

References

[1] S.Santra et. al, Physics Letters B 677 (2009) 139144, and references therein.

[2] S.Santra et. al, PRC 85, 014612 (2012).