Elastic, inelastic and inclusive alpha cross sections in ^{6}Li+^{112}Sn system

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Abstract

Elastic, inelastic and inclusive alpha cross sections have been measured. Coupled-channels calculations by including the couplings of projectile breakup channels and target excitations explain the measured elastic and inelastic data. The inclusive alpha particle production is found to be more than two-third of the total reaction cross section. From coupled-channels calculations, the contribution of α from the non-capture α-d breakup of the ^{6}Li projectile is calculated to be very small. It suggests the possibility of many transfer induced breakup channels, having α as one of the breakup fragments, to be responsible for such a large α particle production.

1 Introduction

Study of nuclear reactions involving weakly bound projectiles is very interesting because of the observation of several unusual features compared to the case of strongly bound projectiles. Suppression of complete fusion, breakup threshold anomaly in optical potential describing elastic scattering, large production of alpha particles in the reactions and larger peak to valley ratio of the fission fragment mass distribution at sub/near barrier energies are some of those interesting observations [1–4]. Projectile breakup in the field of a target nucleus is known to play an important role in the manifestation of all the above features. To understand the underlying reaction mechanism, the experimental data on projectile breakup cross section is thus very important to compare with the coupled-channels calculations that include the breakup channels. In order to constrain the values of coupling parameters and the potentials in the coupled-channels calculations it is also important to reproduce simultaneously the experimental data for as many reaction channels as possible for the same target+projectile system.

With the above motivation it was planned to measure the elastic, inelastic, transfer and breakup cross sections simultaneously for a system involving weakly bound projectile ^{6}Li and a target ^{112}Sn at a near-barrier energy. Choosing ^{112}Sn as a target has two advantages: i) the inelastic states of the target are well separated from its ground state compared to other isotopes of Sn and ii) the Q-value of the transfer induced breakup cross sections are favorable. Although the experimental data on elastic scattering for the above system at several energies are available in the literature but there is no data on inelastic and other reaction channels at those energies available.

2 Experimental details

The angular distributions for elastic, inelastic and inclusive alpha cross sections for ^{6}Li+^{112}Sn system have been measured at a bombarding energy of 30 MeV using BARC-TIFR Pelletron facility at Mumbai. Four telescopes of single Si detectors, placed at 10^o apart, on a rotatable arm inside a 1.5 m diameter scattering chamber were used to detect the light charged particles in the angular range of $\theta_{\rm lab} = 40^o - 140^o$. Each telescope consists of a ΔE detector of thickness $\sim 50\mu$m and a E-detector of $\sim 1500 - 2000\mu$m. A typical 2-dimensional (ΔE-E) spectrum acquired using a single telescope at $\theta_{\rm lab}$=100^o is shown in Fig. 1(a). The one dimensional projection spectra for ^{6}Li, α and deuteron particles are shown in Fig. 1(b), Fig. 1(c) and Fig. 1(d) respectively. Along with the elastic peak, the yields of two inelastic states corresponding to 1st two excited states of target i.e., 2^+ (1.25 MeV) and 3^- (2.35 MeV) states are dominant. For the alpha and deuteron yield, broad spectra of width $\sim$6.4 MeV and $\sim$3.4 MeV peaking at energies corresponding to the beam velocity are observed implying a major contribution could possibly coming from projectile breakup channels.

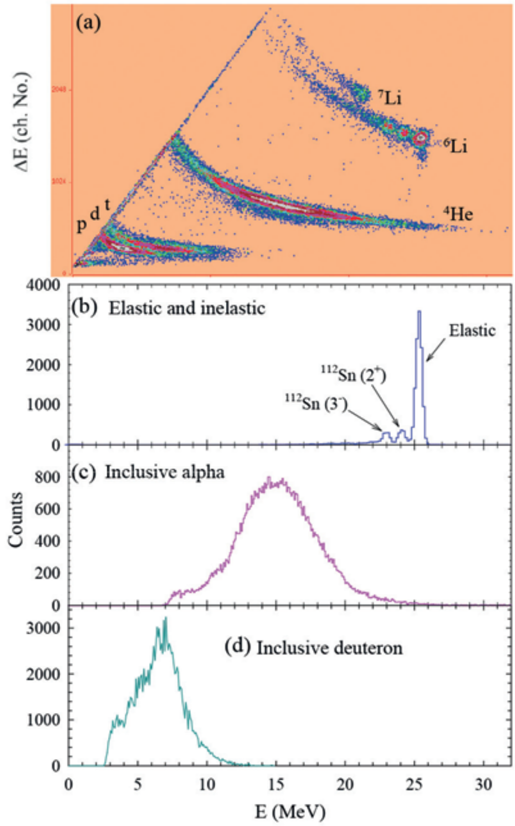

Figure 1: Typical 2-dimensional (ΔE-E) spectrum acquired using a single telescope at θ_{lab}=100^o for ^{6}Li+^{112}Sn reaction at E$_{\rm lab}$=30 MeV is shown in upper panel (a). One dimensional projections of ^{6}Li, alpha and deuteron particle spectra are shown in panel (b), (c) and (d) respectively.

3 Elastic and inelastic scattering

Differential cross sections for the elastic scattering angular distributions normalized to the Rutherford cross sections are shown in Fig. 2(a). The inelastic cross sections corresponding to ^{112}Sn(2$^+$,1.256 MeV) and ^{112}Sn(3$^-$,2.355 MeV) are shown in Fig. 2(b) and (c) respectively. Optical model (OM) analysis using SNOOPY code has been made to fit the elastic scattering data and a total reaction cross section of 914 mb is obtained. To include the effect of breakup coupling, continuum discretized coupled channels (CDCC) calculations using the code FRESCO have been performed using cluster-folded (CF) potential. The potential parameters for fragment target interactions i.e., α+^{112}Sn (d+^{112}Sn) are taken from Ref. [5] ([6]). An overall factor of

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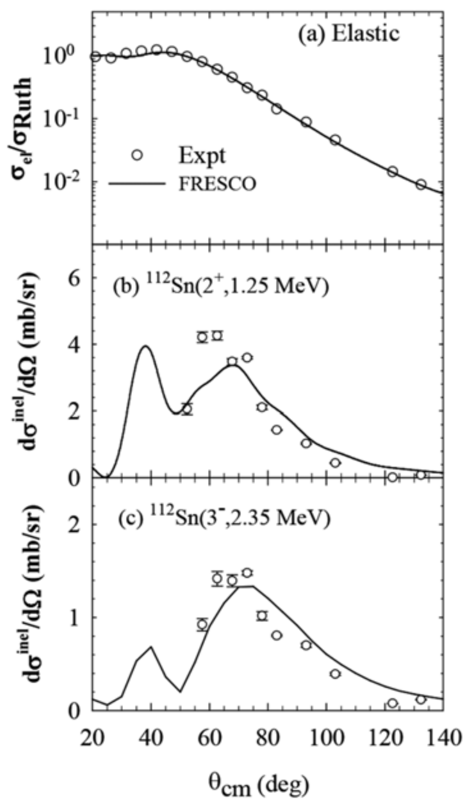

Figure 2: Experimental differential cross sections for (a) elastic scattering and (b,c) inelastic scattering corresponding to (2+, 1.256 MeV) and (3-, 2.35 MeV) excited states of ^{112}Sn respectively. Solid lines correspond to the results of coupled-channels calculations using FRESCO.

0.8 has been multiplied to the CF potential in order to reproduce the elastic scattering angular distribution. The projectile excitation details and the binding potentials of $\alpha - d$ cluster are taken to be same as in Ref. [1]. Since projectile breakup states and target inelastic excitations cannot be coupled together, the calculations are done in two steps. First CDCC calculations are performed. Next, CDCC generated polarization potential is added to CF potential to get an effective potential which in turn is used in the coupled reaction channels (CRC) calculations by FRESCO including the elastic and the target inelastic states only. The coupling parameters available in the literature [7,8] have been used for the two inelastic states. The results of the FRESCO calculations along with the measured data are shown in Fig. 2 as solid lines.

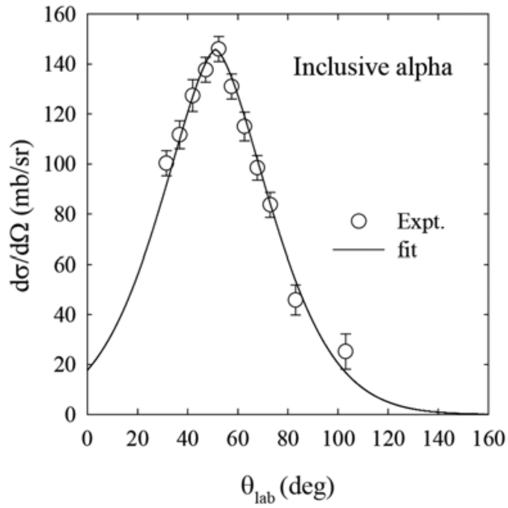

Figure 3: Angular distribution of inclusive alpha cross section. Solid line represents the fit to the measured data to obtain angle-integrated cross section.

4 Inclusive alpha

The measurement of inclusive alpha particle production in the present reaction is another interesting area. As mentioned earlier and shown in Fig. 1, a large alpha yield with velocity equal to that of the incident beam is observed compared to its complementary breakup fragment 'd'. The angular distribution of the inclusive alpha cross section is extracted and shown in Fig. 3. An arbitrary fit that describes the measured data well (shown as a solid line) is applied and the angle-integrated inclusive alpha cross section of 647±35 mb is obtained. This is more than two-third of the total reaction cross section (914 mb). From the CDCC calculations, the non-capture breakup cross section of ^{6}Li$\rightarrow \alpha$+d is found to be only $\sim$60 mb. The rest of the inclusive alpha cross section could be originated from several other reactions [3] e.g., (i) ^{6}Li $(-1n) \rightarrow {}^5$Li$\rightarrow \alpha$+p (ii) ^{6}Li $(+d) \rightarrow {}^8$Be$\rightarrow \alpha + \alpha$ (iii) ^{6}Li$\rightarrow \alpha$+d followed by d capture, etc.

5 Summary

The differential cross sections for elastic, inelastic and inclusive alpha have been measured for ^{6}Li+^{112}Sn system at a beam energy of 30 MeV. Coupled-channels calculations are performed to include the effect of projectile breakup and target excitations. The normalized cluster-folded potential that explains simultaneously the elastic and two inelastic states are used to calculate the projectile breakup cross sections. The calculated non-capture breakup cross section of ^{6}Li→ α+d is found to be very small compared to the inclusive alpha yield suggesting possible α contributions from various transfer induced breakup channels. Detailed calculations and measurements of some of these channels are underway to understand the various reaction mechanisms that are responsible for such a large inclusive alpha cross section.

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