Breakup reactions: effect on the above-barrier complete fusion

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Introduction

In interaction of light, weakly bound nuclei such as ^{6,7}Li, ^{9}Be with heavy targets, complete fusion cross sections are found to be suppressed by 25-35% compared to both theoretical expectations and to measurements for strongly bound [1]. Due to low breakup threshold, these nuclei can breakup into their cluster constituents ($^{6}Li \rightarrow \alpha - d$, $^{7}Li \rightarrow \alpha - d$, ^{9}Be $\rightarrow \alpha - \alpha - n$) before the classical turning point and hence lead to suppression of complete fusion at above-barrier energies. Thus the breakup reaction mechanism of these weakly bound nuclei is crucial to explain the measured above-barrier suppression. In the experimental measurements aimed to understand breakup reactions mechanism, it is observed that reaction dynamics with these nuclei is extremely complicated and interesting. The dominant mechanism of breakup was found to be population of unbound states of nearby nuclei after transfer of one/few nucleons rather than direct breakup into cluster constituents [2, 3].

Complete fusion measurements of these projectiles with light targets are scarce and not very conclusive [1]. This is simply because it is not possible to unambiguously separate the complete fusion products (evaporation residues) from incomplete fusion and transfer products in this mass region. The alternative is to make breakup measurements at sub-barrier energies and then use a theoretical model to predict complete fusion suppression at above-barrier energies.

Experimental details

The experiments were performed using ^{6,7}Li and ^{9}Be beams from the 14UD tandem accelerator at the Australian National University, incident on isotopically enriched thin targets across the nuclear chart [2, 3, 5]. Breakup fragments were measured at sub-barrier energies in coincidence using the BALiN detector array. The array consists of four double sided silicon strip detectors (DSSDs), each 400 μm thick with 16 arc and 8 sectors. The array was placed in a front-back geometry for light targets and in a lampshade configuration (all four detectors placed in backward hemisphere) for heavy targets due to different reaction kinematics.

Data Analysis

In offline analysis, the energy correction for losses was done event by event assuming the target centre to be the point of interaction. For three body kinematics, using energy and momentum conservation, reaction observables of interest such as Q_{val} (reaction Q-value), E_{rel} (relative energy between fragments), θ_{12} (angular opening between breakup fragments), β (breakup angle for α particles in ejectile rest frame assuming breakup occurs asymptotically) and many others were extracted. Q_{val} provides information about the various states of the recoiling nucleus being populated in breakup reaction. Excitation energy of the projectile-like nucleus is shared by the breakup fragments in the form of their kinetic energies. Useful information about excitation energy of the projectile-like nucleus can be extracted by using E_{rel} distribution. Fig. 1 shows Q_{val} vs. E_{rel} histograms in interactions of ^{6}Li with ^{208}Pb and ^{58}Ni. By plot-

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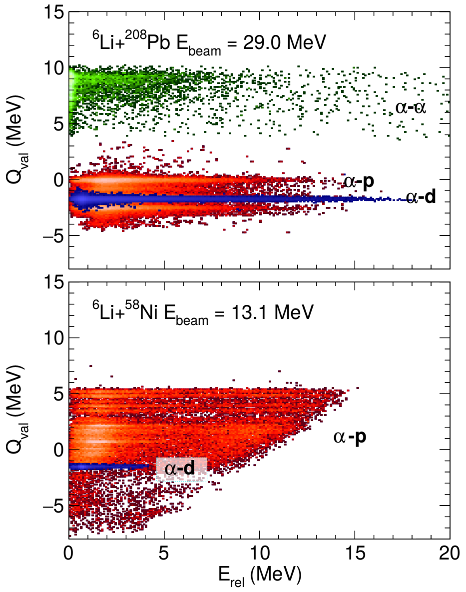

FIG. 1: Two-dimensional plot between Q_{val} and E_{rel} in interactions of ^6Li with ^{208}Pb and ^{58}Ni at 29.0 MeV and 13.1 MeV respectively. The green color is for $\alpha - \alpha$, red is for $\alpha - p$ and blue for $\alpha - d$ breakup events.

ting β vs. θ_{12}, one can identify near-target breakup from asymptotic breakup which is crucial for understanding details of breakup reactions dynamics[6].

Results and Discussions

If breakup occurs in close vicinity of the target, then the presence of the target will strongly influence the trajectories of breakup fragments. The correlations between the experimental observables were used to extract the information on the breakup time scales[5]. The lifetime of the resonant states will determine the breakup locations (close to the target if the state is very short-lived, or far away asymptotically if it is very long-lived) [6]. The projectile-like nucleus can also directly breakup via excitation of non-resonant continuum states in the presence of the Coulomb and/or nuclear field of the target. A modified version of the Monte Carlo classical trajectories code PLATYPUS [4] was used to carry out simulations of sub-barrier breakup reactions which simulates and tracks the trajectories of fragments following breakup reactions. The excitation energies of populated resonant or non-resonant states of the projectile-like nucleus are randomly sampled from a given excitation energy dependent mean lifetime distribution.

The effect of having a finite lifetime even if of the order of reaction time scales ($\sim 10^{21}$ s) is that the point at which the projectile-like nucleus breaks up into cluster constituents is changed. The major effect will be for events where projectile-like nucleus is populated to short-lived resonant or non-resonant states at a point before the classical turning point as now they will cross the turning point and will be on the outgoing trajectories by the time projectile-like nucleus eventually decays. In that case, the above barrier suppression predictions will change because it is the breakup occurring before passing inside the fusion barrier radius which is expected to suppress the above barrier fusion cross sections[7].

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