

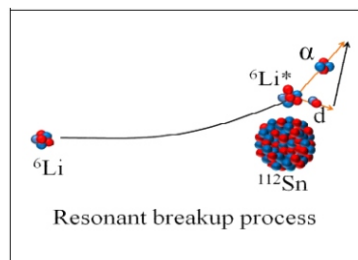
नाभिकीय अभिक्रिया

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$^{6,7}\text{Li}$ एवं ^9Be जैसे दुर्बल-बंध प्रक्षेपास्त्रों से जुड़ी अभिक्रियाएँ

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अनुनादी विभंजन प्रक्रम

सारांश

भापअ केंद्र-टीआईएफआर पेलेट्रॉन लीनॉक (एलआईएनएसी) सुविधा, मुंबई में मध्यम से भारी द्रव्यमान के कई लक्षित नाभिकों पर दुर्बल-बंध $^{6,7}\text{Li}$ और ^9Be प्रक्षेप्यों को शामिल करते हुए विशिष्ट एवं समावेशी मापन किए गए श्रृंखला के कई अनोखे परिणाम दृष्टिगत हुए हैं। इन प्रक्षेपकों के कई नए प्रक्षेप्य विभंजन मोड एवं नए समूह संरचनाओं की खोज की गई। प्रक्षेप्य के अनुनाद एवं गैर-अनुनाद विभंजन के तरीकों, संलयन अभिक्रियाओं, प्रत्यास्थ प्रकीर्णन, पूर्ण एवं अपूर्ण संलयन अनुप्रस्थ काट पर समूह संरचना के भूमिका की जांच की गई। प्रक्षेप्य को विभंजन की ओर ले जाने वाली अल्प-विभंजन सीमा ने प्रत्यास्थ प्रकीर्णन के साथ-साथ सभी अभिक्रिया चैनलों पर भारी प्रभाव दर्शाया है।

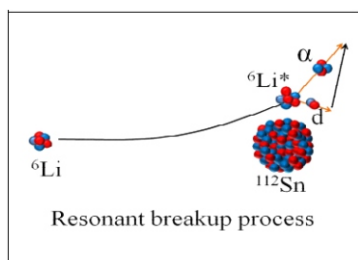
Nuclear Reactions

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Reactions involving Weakly-bound Projectiles like $^{6,7}\text{Li}$ and ^9Be

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Resonant Break-up Process

ABSTRACT

A series of exclusive & inclusive measurements involving weakly bound $^{6,7}\text{Li}$ and ^9Be projectiles on several target nuclei of medium to heavy masses have been carried out at BARC-TIFR Pelletron LINAC facility, Mumbai leading to many interesting results. Several new projectile breakup modes and new cluster structures of these projectiles were discovered. The role of cluster structure of the projectile on its resonant and non-resonant breakup modes, fusion reactions, elastic scattering, complete and incomplete fusion cross sections were investigated. The low breakup threshold leading to the breakup of the projectile showed a huge impact on elastic scattering as well as all the reaction channels.

KEYWORDS: Weakly bound projectiles, resonant & non-resonant breakup, cluster structure, complete & incomplete fusion, transfer reaction, coupling effect

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Introduction

The study of reactions involving weakly bound stable projectiles such as ${}^6,7\text{Li}$ and ${}^9\text{Be}$ provides an opportunity to study nuclear reactions very similar to radioactive ion beams because of their similarities in low breakup threshold energies of the valence nucleons and cluster structures. Hence, compared to the reactions involving tightly bound projectiles, these reactions are accompanied additionally with projectile breakup channels. The identification of various breakup channels in a reaction and their possible effects on reaction dynamics make the study very interesting and challenging.

Understanding the reaction mechanisms of weakly bound projectiles and the coupling of their breakup on various reaction channels is very important, especially in the context of the increasing number of the radioactive ion beam facilities and the quest for super heavy elements by the fusion of nuclei near the drip line.

In recent years extensive studies have been carried out for the reactions involving the above weakly bound projectiles with different target nuclei. Results of some of these studies are highlighted below.

Resonant and Non-resonant Breakup of ${}^{6,7}\text{Li}$

A series of measurements involving all the three projectiles on several target nuclei of medium to heavy masses have been carried out at Pelletron-LINAC facility, Mumbai. Majority of these work during last 10 years focused on the exclusive measurements of two breakup fragments in coincidence to investigate the possible dominant breakup modes. During the process, many new breakup channels have been identified and their cross sections have been measured, particularly in the reactions ${}^6\text{Li}+{}^{112}\text{Sn}$ and ${}^7\text{Li}+{}^{112}\text{Sn}$.

For exclusive measurements, where the coincidence yield is expected to be very low, two large area Si-Strip-Detector Arrays with a maximum angular coverage of ~ 100 degree has been setup as shown in Fig.1. The strip detector arrays consist of ten to fourteen strip detectors, each of which has 16 horizontal and 16 vertical strips. This leads to a total of 1280 and 1792 pixels of the two detector arrays respectively for sensing the position of the detected particles. Number of electronic signals collected from each strip telescope is 48 that lead to a total of 240-336 signals from the full strip detector arrays. Both the projectiles (${}^{6,7}\text{Li}$) can breakup into two fragments by any of the following processes: (i) Direct breakup (ii) Resonant breakup or (iii) Transfer-breakup. Several resonant breakup channels have been observed for the first time. For example, the breakup of ${}^6\text{Li}$ into $\alpha+d$ through its 3rd resonance state 1⁺(5.65 MeV) (see Fig.2, left panel) [1], the breakup of ${}^7\text{Li}$ into $\alpha+t$ through its 2nd resonance state 5/2⁻(6.67 MeV) (see Fig.2, right panel) [2] and breakup of ${}^8\text{Be}$ into 2 alpha through the 3rd resonance state 4⁺(11.31 MeV) in the reaction (${}^7\text{Li}, {}^8\text{Be} \rightarrow 2\alpha$) [3]; all of them have been observed for the first time. In addition, the observation of ${}^6\text{He}+p$ breakup suggests of a new possible cluster structure ${}^7\text{Li}$ as ${}^6\text{He}+p$ [2] other than that of the well-known ${}^4\text{He}+{}^3\text{H}$ and ${}^6\text{Li}+n$ structures. Cross sections for direct and resonant breakup of radioactive ${}^7\text{Be}$ nuclei produced in a transfer reaction ${}^{112}\text{Sn}({}^6,{}^7\text{Li}, {}^8\text{Be} \rightarrow \alpha+{}^3\text{He}){}^{111}\text{In}$ have been measured. Breakup of ${}^7\text{Be}$ into α and ${}^3\text{He}$ cluster fragments via its resonant states of 7/2⁻(4.57 MeV) and 5/2⁻(6.73 MeV) in the continuum have been identified for the first time using the measured distribution of α - ${}^3\text{He}$ relative energy and the reaction Q value obtained from the α - ${}^3\text{He}$ coincident events. Significant cross sections for breakup of ${}^7\text{Be}$ into its cluster fragments directly or through resonant states highlight the importance of the

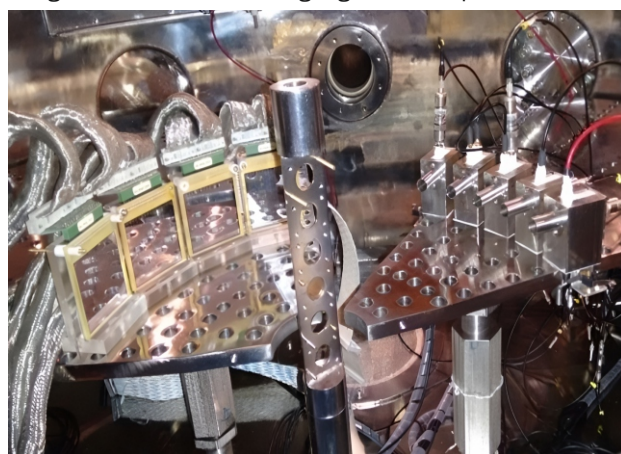


Fig.1: Typical detector setups inside the scattering chamber consisting of 5 sets of single telescopes and 7 (5) sets of strip telescopes, shown in left (right) panel, used for the breakup cross section measurements.

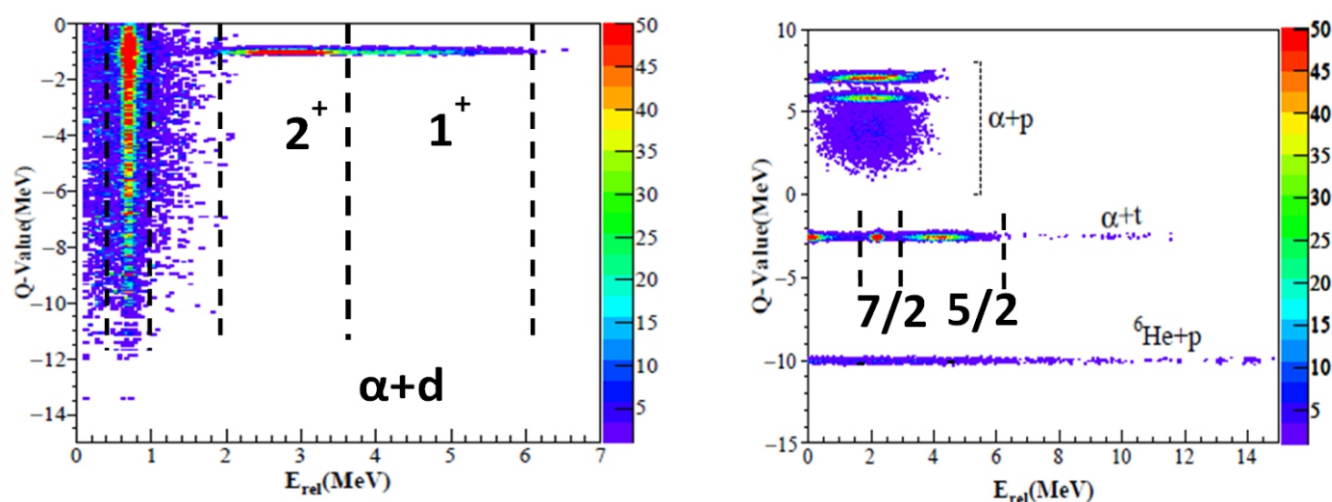


Fig.1: Q-value versus relative energy plots corresponding to breakup of ${}^6\text{Li}$ $\alpha+d$ via 3^+ , 2^+ and 1^+ resonances (left panel) and ${}^7\text{Li} \rightarrow \alpha+t$ via $7/2^-$ and $5/2^-$ resonances (right panel).

ground-state structure of ${}^7\text{Be}$ as a cluster of α and He [4]. All the above observations of breakup through higher resonances have been possible due to the use of the large area Si Strip Detector Arrays. Another interesting observation is that, in all of the breakup modes, one of the breakup fragments is an alpha particle. By measuring as many such channels as possible and estimating the cross sections of the remaining non-measurable alpha producing channels together we have tried to understand the reaction mechanism of large inclusive alpha cross sections for each of the reactions.

Breakup Capture Cross sections

Role of various cluster structures of ${}^7\text{Li}$ in the dynamics of fragment capture was studied for the first time from the particle gamma coincidence measurement. A detailed analysis of the measured yields of the evaporation residues for different excitation energies (E^*) of the composite system based on a new dynamical classical trajectory model were performed. These calculations, constrained by the measured fusion, ${}^4\text{He}$ and ${}^3\text{H}$ capture cross-sections, unambiguously illustrate a two-step process - breakup followed by fusion in the case of the capture of ${}^3\text{H}$ and ${}^4\text{He}$, while in the case of ${}^6\text{He}+p$ and ${}^5\text{He}+d$ configurations massive transfer arising from bound states is inferred to be the dominant mechanism. This work clearly demonstrated the role played by the cluster structure of ${}^7\text{Li}$ in understanding the reaction dynamics at energies around the Coulomb barrier [5].

Non-capture versus Capture Cross sections

Reaction dynamics involving weakly bound nucleus ${}^7\text{Li}$, populating the continuum states, was studied by performing particle-particle (using Si-Strip detector array) and particle -

gamma (using Si-detector telescope + INGA array) coincidence measurements. For the first time simultaneous investigation of all the major reaction processes, breakup, nucleon transfer followed by breakup, and fragment capture reaction channels along with elastic scattering and fusion reaction. The rather complete nature of the data set combined with state of the art theoretical calculations has improved the understanding of the reaction dynamics involving weakly bound stable nuclei and provided an important benchmark for future experiments with radio-active ion beams that are available in low intensities [6,7].

Cluster Transfer versus Breakup Fusion

The origin of the large α particle production and incomplete fusion in reactions involving weakly-bound $\alpha+x$ cluster nuclei still remains unresolved. While the (two-step) process of breakup followed by capture of the “free” complementary fragment (x) is widely believed to be responsible, a few recent studies suggest the dominant role of (direct) cluster stripping. To achieve an unambiguous experimental discrimination between these two processes, a coincidence measurement between the outgoing α particles and γ rays from the heavy residues has been performed for the ${}^7\text{Li} (\alpha+\text{triton})+{}^{93}\text{Nb}$ system. Proper choice of kinematical conditions allowed for the first time a significant population of the region accessible only to the direct triton stripping process and not to breakup followed by the capture of the “free” triton (from the three-body continuum). This result, also supported by a cluster-transfer calculation, clearly establishes the dominance of the direct cluster-stripping mechanism in the large alpha production [8].

Complete and Incomplete Fusion

The complete and incomplete fusion cross sections for the ${}^7\text{Li} + {}^{124}\text{Sn}$, ${}^{205}\text{Tl}$ reactions [9-11] were measured using online and offline characteristic γ -ray detection techniques. A simultaneous explanation of complete, incomplete, and total fusion (TF) data was also obtained from the calculations based on the continuum discretized coupled channel method. Similar measurements performed with ${}^6\text{Li}$ having lower breakup threshold gave higher incomplete fusion cross-section. The total fusion cross section ratio between ${}^6\text{Li}$ and ${}^7\text{Li}$ induced reactions shows an increasing trend as the energy decreases below the barrier while it remains unity at above-barrier energies.

Summary

The exclusive and inclusive measurements involving weakly bound ${}^{6,7}\text{Li}$, and ${}^9\text{Be}$ projectiles on series of target nuclei of medium to heavy masses have been carried out at Pelletron-LINAC facility, Mumbai leading to many interesting results. Several new projectile breakup modes and new cluster configurations of these projectiles were discovered. The role of the cluster structures of the projectiles on the resonant and non-resonant breakup modes, fusion reactions, elastic

scattering, complete and incomplete fusion cross sections were investigated. The low breakup threshold leading to the breakup of the weakly bound projectiles showed a huge impact on elastic scattering, fusion and several other reaction channels.

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