Effect of Breakup on the Elastic Scattering and Fusion Mechanism of Weakly Bound Projectile

A Synopsis Submitted

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सत्यं शिवं सुन्दरम्

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Introduction

The dynamics of weakly bound projectiles have been a topic of keen interest [1-3] due to their low breakup threshold properties. Weakly bound projectiles (WBP) are those nuclei which are having their B.E./nucleon around 1.5-2.5 MeV or even lesser viz. ^{6}Li (1.47 MeV), ^{7}Li (2.48 MeV), ^{9}Be (1.57 MeV) etc. The various reaction channels thus may have the influence on breakup as compared to that of tightly bound nuclei (B.E./nucleon varies from 6-8 MeV). With the advancement of technology, the studies related to even radioactive ion beams (^{6}He, ^{7}Be, ^{8}Li, ^{8}B, ^{11}Li, etc.) also have been explored in detail. Also, it is suggested that the properties of stable weakly bound projectiles are similar to that of unstable ones and thus it is mandatory to study them in detail. Apart from that the availability of high intensity of stable WBP beams in comparison to unstable ones provide better statistics which avail a detailed interpretation of experiments and a better theoretical description can be modeled. Reaction channels show a strong coupling among them around the barrier energy and study in the region becomes interesting considering the following aspects: (i) To probe the energy dependence of optical model potential parameters in elastic scattering (ii) to probe enhancement/suppression of complete fusion (CF) compared to coupled channel calculations.

The energy dependence of phenomenological optical potential at the barrier displays Threshold Anomaly (TA) behavior for tightly bound systems [4,5]. The imaginary component shows the quick closing of inelastic channels, but the real component shows a bell-shaped peak in the same energy range. The real potential is given as $V=Vo+\Delta V$ where ΔV energy dependent attractive part of potential which is responsible for demonstrating the coupling of various inelastic channels with elastic channels, resulting in an enhancement of the real component of the potential to peak around the barrier. On the other hand, for weakly bound projectiles the imaginary potential resists drop in the barrier area and exhibits an elevation that may be stable even when the bombarding energy decreases, implying that the breakup cross section is especially important below the Coulomb barrier. This contributed to the rise in the imagined component of potential, which again was coupled with a decrease in the real part. This unexpected reliance is referred to as Breakup Threshold Anomaly (BTA) [6, 7]. Several studies have been performed to understand the barrier behavior of weakly bound nuclei viz. interaction of ^{6}Li with targets of almost all mass range nuclei has been reported to show Breakup Threshold Anomaly (BTA) behavior ^{27}Al [8], ^{58}Ni [9], ^{80}Se [7], ^{112,116}Sn [10], ^{144}Sm [11], ^{208}Pb [12]. In case of ^{28}Si [13, 14] a contradictory observation still exists. However, more studies are needed on the lighter mass side before a clear conclusion can be reached. For weakly bound projectile ^{7}Li, various mass ranges show results without coordination and a generalized conclusion is still difficult to be drawn. For example, the absence of TA was observed for ^{7}Li with lighter medium mass ^{27}Al [15, 16], ^{28}Si [17] while just little heavier ^{59}Co [18], ^{80}Se [19] have reported TA. Medium heavy mass ^{144}Sm [20] and ^{159}Tb [21] don’t show TA but ^{138}Ba [22] which is in the same mass range show TA behavior. The heavy mass targets like ^{7}Li on ^{208}Pb [23] and ^{232}Th [24] have confirmed the appearance of TA.

Further, enhancement/suppression of fusion cross section is discussed in terms of coupling to other reaction channels and breakup as a significant channel in the case of weakly bound projectiles. Thus, while channels such as transfer and inelastic excitation may increase the fusion cross section, channels such as breakup may limit total flux for fusion. According to inclusive and exclusive investigations for alpha-production, large alpha cross section is a related phenomenon with the breakup and transfer channels [25, 26]. It is observed that weakly bound projectiles having cluster structure ‘α+x’ tend to produce larger alpha compared to other fragment x via various channels. Several reports [25-30] regarding inclusive and exclusive measurements are contributing to understand large inclusive alpha production however complete understanding of phenomenon is still an open question to the community.

Objective of thesis

In the present work, the main objective has been to understand the effect of breakup on reaction dynamics of the weakly bound projectile (WBP) near the Coulomb barrier on various reaction channels such as elastic scattering, transfer, etc. with help of experimental and theoretical techniques. In the view of investigation of mentioned objective, two experimental measurements have been carried out involving WBP ^{6}Li and ^{7}Li on medium heavy mass targets ^{51}V and ^{92,100}Mo.

The first experiment was aimed at measurements of elastic scattering and transfer channel studies around the barrier energies for the system ^{6}Li+^{51}V, using 14 UD BARC-TIFR Pelletron, Mumbai, India [31, 32]. The data has been analyzed using SFRESCO code. The theoretical breakup studied were done using FRESCO code.

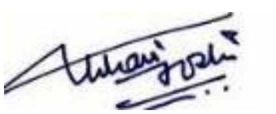
The second experiment was conducted for measurements of elastic scattering and its dependence on target deformation around the barrier energies for the systems ^{7}Li+^{92,100}Mo, using 15 UD Inter-University Accelerator Centre (IUAC) Pelletron, New Delhi, India [33]. The data has been analyzed using SFRESCO code. The theoretical breakup studied were done using FRESCO code [34]. In the same setup one more projectile ^{6}Li was utilized to get measurement of elastic scattering angular distribution for the system ^{6}Li+^{100}Mo and data analysis was done by SFRESCO code.

Plan of thesis

The present thesis has been organized into six chapters as given below:

Chapter 1 provides a brief introduction about the nuclear reactions and their mechanism. A broad discussion about different types associates during a nuclear reaction is presented. The influence of projectile selection like heavy ion projectile or weakly bound projectile has been discussed to prepare the base of the thesis. The chapter takes care of a broad discussion of weakly bound projectiles like ^{6,7}Li, ^{9}Be, etc. and their role in understanding their special impression on the mechanism of reaction taking place. The objective of the thesis is established. **Chapter 2** describes the role of an accelerator in a nuclear reaction, its construction detailing, and the practical implementation of its usage for research purposes. Further, the necessity of a detector and its fundamental role during the interaction of a charged particle with matter is explained in detail. Apart from experimental necessities, theoretical tools for calculations are also described. In this view, nuclear reaction models and potential undertaken for analysis are discussed in detail. To look over the consistency of results, different kind of models and potentials are utilized independently. A detailed discussion of theoretical calculations supporting the understanding of the objective of the thesis like energy dependence of potential, the breakup of the projectile, the reaction mechanism of various channels, etc. is presented in broad. **Chapter 3** describes of the elastic scattering studies for system ^{6}Li+^{51}V. The experimental details followed by data analysis using different potentials and simultaneous description of data using Continuum Discretized Coupled Channel calculations (CDCC) is discussed. Study of potential behavior in the double folding framework from density distribution to understand anomaly. Systematics of all available measurements to generalize threshold behavior and cross section for

^{6}Li is shown. **Chapter 4** details broadly on the measurements of angular distribution and energy spectrums of the alpha and deuteron through various reaction channels viz. breakup, transfer, and incomplete fusion are studied to investigate their relative contributions to a reaction. **Chapter 5** details the elastic scattering angular distribution for system ^{7}Li+^{92,100}Mo. Analysis of data in Wood Saxon potential and São-Paulo potential frameworks. Threshold anomaly behavior in both of these frameworks. Theoretical description of data with CDCC calculations. A systematic behavior study with present measurements also is to be done. Some quasielastic barrier distribution studies are done. For more clear picture we are waiting for another beam time. **Chapter 6**, The elastic scattering studies for system ^{6}Li+^{100}Mo. Data analysis using optical model potential with description of data by SFRESCO fitting. Study of the energy dependence of potential to understand anomaly around the barrier. **Chapter 7**, depicts a brief summary of research work carried out in the present thesis along with the future outlooks.



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Ph.D. Research Fellow Ph.D. Supervisor

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PUBLICATIONS

❖ International Journal (Published) :

1. **Inclusive *α* production for the ^{6}Li + ^{51}V system**

   C. Joshi, H. Kumawat , V. V. Parkar , D. Dutta, S. V. Suryanarayana, V. Jha, R. K. Singh, N. L. Singh, and S. Kailas

   Phys.Rev. C 105, 034615 (2022)

2. **Exploring breakup coupling effect in ^{7}Li+^{92,100}Mo elastic scattering around Coulomb barrier energies**

   C. Joshi, H. Kumawat, R. K. Singh, N. L. Singh, D. Patel, B. K. Nayak, J. Acharya, A. Parihari, K. Rani, S. D. Sharma, G. Kaur, I. Ahmed, K. S. Golda, N. Saneesh, M. Kumar, A. Jhingan , P. Sugathan

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3. **Elastic scattering for 6Li+51V and systematic study of breakup threshold anomaly**

   H.Kumawat,**C.Joshi**,V.V.Parkar,V.Jha,B.J.Roy, Y.S.Sawant, P.C.Rout, E.T.Mirgule, R.K.Singh, N.L.Singh, B.K.Nayak, S.Kailas

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4. **Elastic scattering and boron, lithium, and α-particle production in the ^{9}Be + ^{51}V reaction**

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5. **Re-measurement of reduced transition probabilities in 132Ba***

S. Dutt, M. Saxena, R. Kumar, A. Jhingan, A. Agarwal A. Banerjee, R.K. Bhowmik, **C. Joshi** , J. Kaur, A. Kumar M. Matejska-Minda, V. Mishra, I.A. Rizvi, A. Stolarz H.J. Wollersheimi, P.J. Napiorkowski

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6. **No evidence of reduced collectivity in Coulomb-excited Sn isotopes**

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7. **Experimental study of the transfer-induced fission fragment angular distribution in the $^{6}Li + ^{238}U$ reaction**

A.Parihari, G. Mohanto, Gurpreet Kaur, A. Jhingan, K. Mahata, R. G. Thomas, P. C. Rout, E. T. Mirgule, V. V. Desai, B. Srinivasan**, C. Joshi**, V. Mishra, M. Kushwaha, Shilpi Gupta, D. Sarkar, S. V. Suryanarayana, A. Shrivastava, N. L. Singh, A. Misra, B. K. Nayak, and A. Saxena

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1. **Reaction dynamics of weakly bound stable projectile for system $^{6}Li+^{51}V$**
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2. **Fabrication of Thin Targets of $^{92,100}Mo$**
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3. **Measurement of the cross-section $^{107}Ag(n,2n)^{106}Ag$ reaction on neutron energy 13 MeV and 22 MeV**
   Chhavi Joshi, Ratan k. Singh, Siddharth Parashari,Mayur Mehta,Rakesh Chauhan, Rajnikant Makwana, S.K. Mukherjee, N.L.Singh

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4. **Shape evolution in semi-magic Sn-isotopes: A recent scenario**
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5. **Observation of triaxiality in the transitional ^{132}Ba nucleus via B(E2↑) measurements**
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6. **Exploration of Effects of Nuclear Structure and Reaction Mechanism on the Threshold Behaviour in Nuclear Reactions with Weakly Bound Projectiles: the ^{7}Li + ^{74}Se System**
   U .K. Pal, V.V. Parkar, S. Santra, A. Pal, H. Kumawat , K. Ramachandran, D. Chattopadhyay, A. Kundu, **C. Joshi**, T. N. Nag, G. Mahanto, A. Parihari, S. De, A. Patel3, Hemlatha and B. K. Nayak

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7. **Determination of hexadecapole deformation for ^{160}Gd nucleus using quasi-elastic scattering**
   Sukanya De, G. Mohanto, A. Parihari, E.T. Mirgule, B. Srinivasan, P.C. Rout, M. Kushwaha, S. Arora, **C. Joshi**, A. Sharma, B.K. Nayak and A. Saxena

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8. **Re-evaluation of stable Sn-isotopes: Probing of B(E2↑) values**
R. Kumar, M. Saxena, P. Doornenbal, A. Jhingan, A. Banerjee, R.K. Bhowmik, S. Dutt, R. Garg, **C. Joshi**, V. Mishra, P.J. Napiorkowski, S. Prajapati, P.A. Soderstrom, and H.J. Wollersheim

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9. **Probing the low-level nuclear structure of ^{132}Ba by Coulomb excitation measurements**
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10. **Cross-section measurement of the ^{103}Rh(n,2n)^{102}Rh reaction at 22 MeV Energy**
RatanKumar Singh, Siddharth Parashari, N. L. Singh, RajniKant Makwana, S.K. Mukherjee, Mayur Mehta, Sai Akhil Ayyala, Rakesh Chauhan, **Chhavi joshi**

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11. **Coulomb excitation measurement of ^{132}Ba at IUAC, New Delhi**
S. Dutt, M. Saxena, R. Kumar, A. Jhingan, A. Agarwal, A. Banerjee, R. K. Bhowmik, **C. Joshi**, J. Kaur, A. Kumar, M. Matejska-Minda, V. Mishra, I. A. Rizvi, A. Stolarz, H. J. Wollersheim, and P. J. Napiorkowski

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12. **Transfer Induced Fission Fragment Angular Distribution for ^{6}Li + ^{238}U Reaction**
A. Parihari, G. Mohanto, Gurpreet Kaur, K. Mahata, P.C. Rout, E. T. Mirgule, A. Jhingan, V.V. Desai, B. Srinivasan, **C. Joshi**, V. Mishra, R. Kujur, D. Sarkar, S.V. Suryanarayana, N.L. Singh, M. Kushwaha, Shilpi Gupta, A. Shrivastava, B.K. Nayak and A. Saxena

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