BARC–TIFR Pelletron Linac Facility Beam Time Request @2024

Title of the Experiment: Dynamics of B-induced reaction at low energies

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Local Collaborator: Dr. Suparna Sodaye (BARC)

Note:

- **It is a new proposal. This proposal is a part of the running SERB approved project SPG/2022/000352.**
- **It is also the thesis work of Mr. Bharat Kharpuse, student working in this SERB project.**

Beam details: ^{10,11}B, 25-70 (MeV), Maximum available Beam Energy and Current, 30^{o} N Cascade hall

Buncher requirement: ~~Yes~~/ No

Number of shifts (1 shifts=8 hr.) required: 12 Shifts

Experiment details:

1. **Objective/Motivation of Experiment:**

Nuclear reactions involving tightly and loosely bound nuclei impact the interaction phenomenon differently. Complete fusion (CF) results from strongly bonded nuclei, such as ^{12}C, ^{14}N, ^{16}O, ^{19}F, etc., transferring their complete momentum to the target [1- 4]. On the other hand, in addition to CF, weakly bound nuclei (such as ^{6,7}Li and ^{9}Be) may break into fragments before fusing with the target [5-9]. Although several aspects of heavy-ion fusion dynamics have been reported so far, an in-depth understanding of the effect of entrance channel parameters on fusion dynamics, including mass asymmetry, Coulomb factor, and α-Q value, has not been achieved. An analysis of these factors might improve the reaction models to explain fusion dynamics at low energies.

When projectiles are weakly bound, their fusion cross sections are notably affected by static effects due to their halo structure and dynamic channels, such as breakup, which are typically more pronounced than reactions involving tightly bound nuclei. In the fusion of weakly bound projectiles, fragments after a breakup rom the projectile can interact with the target in various ways: non-capture breakup, Incomplete fusion (ICF), and sequential complete fusion. Although ICF was first observed in reactions with strongly bound projectiles, recent observations at near-barrier energies with weakly bound projectiles have heightened interest in this area [10-14]. Additionally, pre-equilibrium emission of light particles/clusters contributes significantly to heavy-ion reaction dynamics.

The reaction processes like complete-incomplete fusion, deep inelastic scattering, quasi-fission, and others, particularly in low-energy heavy-ion induced reactions, is yet to understand. Recent interpretations of experimental data emphasize the need to distinguish different mechanisms leading to the same final product, especially in reactions involving weakly bound nuclei [15-17]. Exclusive measurements of α-particles and other reaction products are crucial for untangling the various contributing mechanisms. Such measurements, along with differential cross-sections for different reaction processes, provide essential inputs for theoretical calculations necessary for a comprehensive understanding of reactions involving weakly bound nuclei near the Coulomb barrier.

Investigation on the effect of breakup in fusion has mainly focused on reactions with stable beams (like ^{6}Li, ^{7}Li, and ^{9}Be), which have breakup thresholds ranging from 1.45 to 2.45 MeV. However, the ^{10}B nucleus also has a low α-separation energy of around 4.5 MeV, suggesting it may undergo breakup at low excitation energies, significantly impacting fusion mechanisms at low bombarding energies [18,19]. The measurement was carried out with the ^{10,11}B beam and ^{159}Tb target in the energy range 38-72 MeV [18], showing substantial Er nuclei production resulting from the ICF process. The complete fusion cross section was suppressed by 14% at above-barrier energies for the reaction, ^{10}B+^{159}Tb [18]. Similarly, CF cross sections are suppressed by 15% for ^{10}B and 7% for ^{11}B reactions on ^{209}Bi [19]. However, the fusion behaviour of the ^{10}B projectile compared to the ^{11}B fusion remains grossly unexplored in the medium and light mass nuclei.

This proposal aims to measure fusion excitation functions for reactions involving ^{10}B and ^{11}B projectiles and light and medium mass targets (^{89}Y, ^{59}Co, and ^{141}Pr) around their Coulomb barriers and above in the energy range 25 - 70 MeV which covers the energy range 10% below and 40% above their respective coulomb barrier energies. The behaviour of ^{11}B, a strongly bound nucleus with α-separation energy of around 8.6 MeV, will be compared with ^{10}B, expected to exhibit breakup effects due to its low α-separation energy. This comparison will shed light on the correlation between the suppression of complete fusion and the α-breakup thresholds of the projectiles.

Under this proposal, we will focus on the following:

- Study of the ^{10}B and ^{11}B induced fusion reaction on ^{89}Y, ^{59}Co, and ^{141}Pr, by measuring the cross-sections of the residues using off-beam γ-counting method.

References

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Description of Experiment:
Our experiment aims to utilize the offline γ counting method for precise measurements. This method involves two key steps: first, irradiating targets with a particle beam, and second, detecting the γ-rays emitted following the decay of the evaporation residues (ERs).

1. **Activation Measurements:**

For our measurements, we will employ ^{89}Y, ^{59}Co, and ^{141}Pr targets (foils or other forms of targets), each with a thickness ranging ~1mg/cm^2. These targets will be subjected to irradiation using a ^{10,11}B beam. To effectively capture recoiling ERs, we will incorporate aluminum catcher foils with a thickness of approximately 1-2 mg/cm^2 behind each target foil. These aluminum foils will serve a dual purpose: to stop recoiling ERs and act as energy degraders. Monitoring of the beam current will be facilitated by a Faraday cup, with the beam flux determined from the charge collected in the cup.

2. **Post-Irradiation Measurements:**

Our post-irradiation measurements will involve identifying the reaction products halted within the target and aluminum foils. This identification will be accomplished by analyzing their characteristic γ rays through offline measurements. For this purpose, we will utilize the high-purity germanium (HPGe) detector known for its excellent energy resolution. After each activation run, we will carefully remove the stack of target and catcher foil and place them in front of the HPGe detector and measure the γ-ray spectra over a period of time for detailed analysis of the emitted γ-radiation.

Beam Time Requirement:

Beam	**Charge state**	**Target**	**Coulomb Barrier Lab Frame** (MeV)	**Energies in Lab frame (MeV)**	**Irradiation time (h)**
^{10,11}B	$5^+ / 4^+$	^{59}Co	23.03	$25 < E_{Lab} < 60$	76
		^{89}Y	29.9	$28 < E_{Lab} < 66$	
		^{141}Pr	40.7	$36 < E_{Lab} < 70$	

Total irradiation time required = 76 h
Beam setting and tuning time = 8 h
Beam energy changing time = 8 h
Target changing time = 8 h
Total hours required = 100 h
Total shifts required = 12 (minimum for the proposed experiment)

Note: usually beam current is low at low energies, therefore we need minimum 12 shifts.

- Whether the experiment is part of PhD /~~Post Doc~~. Work: **YES**

- Details of Beam time availed of in recent past on this experiment by the PI: **NO Beam time was availed on this proposal. <u>This new proposal is to carry out the running SERB project work</u>**

- **Details of papers published / presented in journals / symposia, etc. based on recent experiments: (since 2021)**

1. Study of ^{9}Be fusion in ^{93}Nb around the Coulomb barrier; Himanshu Sharma, Moumita Maiti, Malvika Sagwal, Rishabh Kumar, Ankur Singh, Suparna Sodaye; Eur. Phys. J. A 60, 64 (2024)
2. Analysis of residual cross sections from ^{14}N+^{93}Nb reaction: Fusion dynamics of a non-α-cluster projectile; Himanshu Sharma, Moumita Maiti, T. N. Nag, and S. Sodaye; Phys. Rev. C 107, 064601 (2023)
3. Measurement of residues from the ^{6}Li + Zn reaction: Analysis of fusion phenomena below 7.1 MeV/nucleon; Ankur Singh, Moumita Maiti, T.N. Nag, S. Sodaye; Phys. Rev. C 108, 024607 (2023)
4. Shell effect driven fission modes in fragment mass and total kinetic energy distribution of ^{192}Hg*; Rishabh Kumar, Moumita Maiti*, A. Pal, S. Santra, Pavneet Kaur, Malvika Sagwal, Ankur Singh, P. C. Rout, Abhijit Baishya, Ramandeep Gandhi, and T. Santhosh; Phys. Rev. C 107, 034614 (2023).
5. Reaction dynamics of the ^{12}C+^{181}Ta system near the Coulomb barrier: Evidence of fusionfission events; Pavneet Kaur, Moumita Maiti, T. N. Nag, and S. Sodaye; Phys. Rev. C, 105, 014629 (2022).
6. Exploring various features of the reaction mechanism involved in the collision of ^{7}Li on Cu; Rishabh Kumar, Moumita Maiti, T.N. Nag, S. Sodaye; Phys. Rev. C 104, 064606 (2021).
7. New measurement of residues from ^{12}C+^{93}Nb by the activation technique: A closer look at the reaction mechanisms; Malvika Sagwal, Moumita Maiti, T.N. Nag, S. Sodaye; Eur. Phys. J. Plus 136, 1057 (2021).
8. Study of excitation functions and insights into the reaction mechanisms of ^{6}Li fusion in Cu; Rishabh Kumar, Moumita Maiti, Gayatri Sarkar, Malvika Sagwal, Pavneet Kaur, Rinku Prajapat, T.N. Nag, and S. Sodaye; Eur. Phys. J. A 57, 209 (2021).
9. Probing the influence of incomplete fusion in ^{6}Li+^{89}Y reaction upto 7.2 MeV/nucleon energy; Rinku Prajapat and Moumita Maiti; Phys. Rev. C 103, 034620 (2021).