# Investigation of nucleon(s) transfer followed by breakup in $^{10}$B+$^{209}$Bi reaction

Prabhat Mishra[1,2],* S. K. Pandit[1,2], V. V. Parkar[1,2], Satbir Kaur[1,2], K. Mahata[1,2], A. Shrivastava[1,2], K. Ramachandran[1], Vineet Kumar[1,2], Arati Chavan[3], Sangeeta Dhuri[1,2], Prasanna M.[4], and S. Rathi[3]

[1] *Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, India*
[2] *Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094, India*
[3] *Vivekanand Education Society's College of Arts, Science and Commerce, Mumbai - 400071, India and*
[4] *Department of Physics, Rani Channamma University, Belagavi - 591156, India*

## Introduction

Recently several exclusive breakup studies have been reported with stable weakly bound $\alpha$ cluster nuclei like $^{6,7}$Li and $^{9}$Be ($S_\alpha <$ 2.5 MeV) [1–5]. A number of interesting observations and features related to breakup of projectile/ejectile in the vicinity of target nucleus have been revealed. In continuation with this, we have initiated similar studies with $^{10,11}$B projectiles which again can be considered as $\alpha$ cluster nuclei with fairly higher $\alpha$ separation energies ($S_\alpha$=4.46 (8.66) MeV for $^{10}$B ($^{11}$B) ) compared to the above mentioned stable weakly bound nuclei. There are very few exclusive charged particle coincidence studies performed for the investigation of $^{10}$B cluster structure [6, 7]. Currently we are doing comprehensive studies of $^{10}$B nucleus with a focus on investigating the role of different cluster structures on reaction mechanism.

We had reported earlier the inclusive $\alpha$ and reaction cross sections measured for $^{10}$B+$^{159}$Tb, $^{197}$Au and $^{209}$Bi systems at 54 MeV beam energy [8]. In the present work, we report the nucleon(s) transfer followed by breakup of ejectile for $^{10}$B+$^{209}$Bi system.

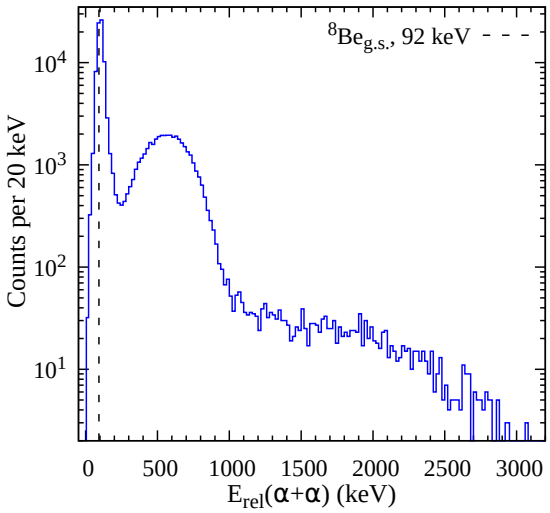


FIG. 1: The measured relative energy spectra between two $\alpha$ particles detected in coincidence for $^{10}$B+$^{209}$Bi reaction at $E_{lab}$=53.7 MeV and $\theta_{lab}$=110°. Dashed line shows the position of events corresponding to the 2$\alpha$ decay of $^{8}$Be ground state.

## Experimental Details

The experiment was performed using $^{10}$B beam of 54 MeV energy using the 14UD BARC-TIFR Pelletron-LINAC Facility, Mumbai. A self-supporting foil of $^{209}$Bi of thickness $\sim$ 1 mg/cm$^2$ was used as target. Beam energy was corrected for the energy loss in half the target thickness and the corrected energy was 53.7 MeV. Five segmented large area $\Delta E$-$E$ type Silicon (Si) strip detector telescopes of active area 5x5 cm$^2$ (thicknesses: $\Delta E \sim$ 30-50 $\mu$m, $E \sim$ 1.0-1.5 mm) and three telescopes consisting of Silicon surface barrier detectors (thicknesses: $\Delta E \sim$ 30-50 $\mu$m, $E \sim$ 300-2000 $\mu$m) were used for the measurement of the outgoing fragments. In Si strip detector telescopes the $\Delta E$ detectors were single-sided with 16 vertical strips, and the $E$ detectors were double-sided with 16 strips on front (horizontal) and 16 strips on the back (vertical).The angular range covered in the present setup was around 30° to 140°. In addition, two Silicon surface barrier detectors (thicknesses $\sim$ 300 $\mu$m) kept at $\pm$ 20°, were used to monitor Rutherford scattering for absolute normalization. The data were collected in an event by event mode, with the trigger generated from the $E$ detectors. Multiplicity threshold was kept at two or more for the measurement of breakup fragments

*Electronic address: pmishra.barc@gmail.com

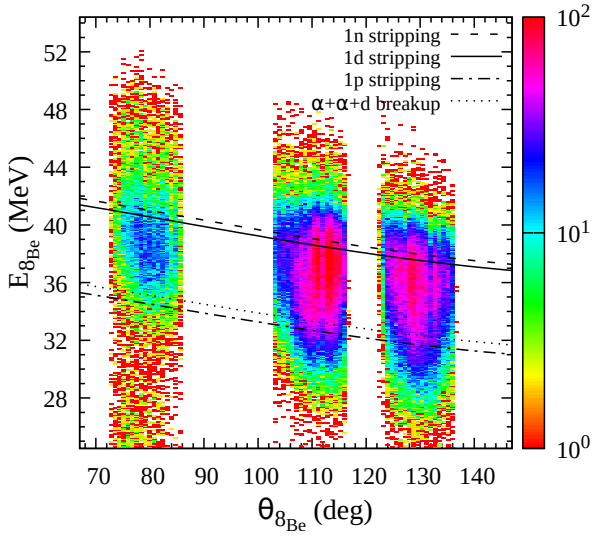


FIG. 2: Reconstructed energy-angle correlation of $^8$Be obtained from coincident detection of $2\alpha$ particles in $^{10}$B+$^{209}$Bi reaction at $E_{lab}$=53.7 MeV. Kinematical lines of $^8$Be are also plotted for $n, d, p$ stripping followed by breakup and ($^{10}B^* \rightarrow \alpha + \alpha + d$) reactions .

in coincidence. Data were recorded in VME based data acquisition system.

## Results and Discussion

All the strips of $\Delta E$ and $E$ detectors were calibrated using known $\alpha$ energies from $^{229}$Th and $^{241}$Am sources. Particles were identified using energy loss information from $\Delta E$ and $E$ detector telescopes. A good charge ($Z$) and mass ($A$) resolution was achieved [8]. The breakup fragments were characterized by their kinetic energy ($E$), identity ($A$,$Z$) and scattering angles ($\theta$,$\phi$) with respect to the beam axis. The relative angles ($\theta_{rel}$) between the fragments were determined from the measured scattering angles ($\theta_1$,$\phi_1$;$\theta_2$,$\phi_2$) of the detected fragments. The fragments' mass ($m_1$,$m_2$), kinetic energy ($E_1$,$E_2$) and relative angle ($\theta_{rel}$) were then used to calculate their relative energy ($E_{rel}$). The measured relative energy spectra between two $\alpha$ particles detected in coincidence for $^{10}$B+$^{209}$Bi system at $E_{lab}$=53.7 MeV and $\theta_{lab}$=110° is shown in Fig. 1. The $E_{rel}$ spectra shows a peak at 92 keV that corresponds to the breakup of ground state of $^8$Be into $2\alpha$ particles.

The energy ($E_{^8Be}$) and angle ($\theta_{^8Be}$) of $^8$Be prior to breakup into two $\alpha$ particles were reconstructed from the energy ($E_{\alpha_1}$,$E_{\alpha_2}$) and scattering angles ($\theta_{\alpha_1}$,$\phi_{\alpha_1}$;$\theta_{\alpha_2}$,$\phi_{\alpha_2}$) of two coincident $\alpha$ particles coming from the breakup of $^8$Be. Reconstructed energy-angle correlation of $^8$Be in $^{10}$B+$^{209}$Bi reaction at $E_{lab}$=53.7 MeV is shown in Fig. 2. Kinematical lines of $^8$Be corresponding to various nucleon(s) transfer processes (as given in Table I) followed by breakup of ejectiles is also shown in Fig. 2. The ejectile breakup modes are: $^9$B ($\alpha$+$\alpha$+p), $^9$Be($\alpha$+$\alpha$+n) and $^8$Be($\alpha$+$\alpha$). The $^{10}$B nucleus can also break into $\alpha$+$\alpha$+$d$ after being inelastically excited above its breakup threshold of 5.94 MeV. The ground state $Q$-values ($Q_{gg}$) and optimum $Q$-values ($Q_{opt}$), obtained from the matching conditions of the semi-classical trajectory, for these reactions are also given in Table I. Dashed, solid and dot-dash lines correspond to the energy of $^8$Be after neutron, deuteron and proton stripping reactions respectively. Dotted line corresponds to $^{10}$B nucleus breaking into $\alpha$+$\alpha$+$d$ after being excited above its breakup threshold. Fig. 2 is indicating that deuteron and neutron stripping reactions followed by breakup of ejectiles are dominant for $2\alpha$ coincident events in $^{10}$B+$^{209}$Bi reaction. Detailed analysis and results of various reaction mechanisms will be presented in the symposium.

TABLE I: $Q_{gg}$ and $Q_{opt}$ values of the stripping reactions contributing to the $2\alpha$ coincident events in the $^{10}$B+$^{209}$Bi reaction.

| Process | Exit Channel | $Q_{gg}$(MeV) | $Q_{opt}$(MeV) |
|---|---|---|---|
| 1$n$ stripping | $^9$B+$^{210}$Bi | -3.83 | 0 |
| 1$p$ stripping | $^9$Be+$^{210}$Po | -1.60 | -9.76 |
| 1$d$ stripping | $^8$Be+$^{211}$Po | 1.28 | -9.76 |

## Acknowledgments

We thank the PLF, Mumbai staff for smooth operation of the machine; Mr. A. Kumar and Mr. P. Patale for help during the experiment. One of the authors (P. Mishra) gratefully acknowledges the financial support from DAE, India for providing the research fellowship.

## References

[1] L. F. Canto *et al.*, Phys. Rep. 424, 1 (2006)
[2] A. Shrivastava *et al.*, Phys. Lett. B 633, 463 (2006)
[3] R. Rafiei *et al.* Phys. Rev. C 81, 024601 (2010)
[4] S. K. Pandit *et al.*, Phys. Rev. C 93, 061602(R) (2016), *ibid* Phys. Rev. C 100, 014618 (2019)
[5] K. J. Cook *et al.* Phys. Rev. C 93, 024601 (2016)
[6] N. Curtis *et al.*, Phys. Rev. C 72, 044320 (2005)
[7] P. J. Leask *et al.*, Phys. Rev. C 63, 034307 (2001)
[8] Prabhat Mishra *et al.*, Proc. of the DAE Symp. on Nucl. Phys. 67, 365 (2023)