Multinucleon transfer reactions in symmetric light system

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I. INTRODUCTION

Cluster structures of various configurations have been observed in light nuclei, representing one of the fundamental aspects of nuclear structure. Recently, cluster models have been found to complement the shell model, especially in describing nuclear reactions, resonances, and decay modes in light nuclei. Although α-clustering is most commonly found in atomic nuclei, other types of clustering are also important. In case of ^{9}Be, well-established cluster configurations include $\alpha+\alpha+n$, ^{8}Be$+n$, and ^{5}He$+\alpha$ [1–3]. In the present work, multi-nucleon transfer reactions have been studied in the ^{9}Be+^{9}Be system with the aim of exploring a possible cluster configuration.

II. EXPERIMENTAL DETAILS

The experiment was carried out at the BARC–TIFR Pelletron–Linac Facility using a 45 MeV ^{9}Be beam incident on a self-supporting ^{9}Be target of thickness $\sim$1 mg/cm^2. Reaction products were measured with an array of four double-sided silicon strip detector (DSSD) telescopes (T1–T4), covering laboratory angles between 20° and 70° on both sides of the beam axis. A schematic of the experimental setup is shown in Fig. 1(a). Each telescope had an active area of 5×5 cm^2 and was mounted at a distance of 13.4 cm, providing substantial solid-angle coverage. Both the ΔE and E detectors were double-sided, segmented into 16 vertical strips on the front and 16 horizontal strips on the back. This configuration enabled two-dimensional position determination with 256 pixels, each having an effective area of $\sim 3 \times 3$ mm^2. The thicknesses of the ΔE detectors were 30 μm for T1–T3 and 40 μm for T4, while the E detectors had thicknesses of 1.5 mm for T1–T3 and 1.0 mm for T4. The data were recorded in event-by-event mode with a VME-based acquisition system. The detectors were calibrated using the known energies of α-particles from ^{229}Th source. Particle identification was performed with the standard ΔE–E technique, based on the measured energy loss in the

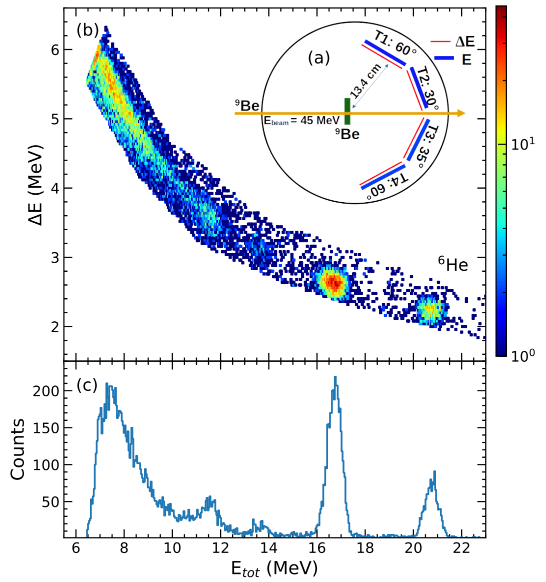

FIG. 1: (a) Schematic representation of the experimental setup with the four DSSD telescopes placed symmetrically on both sides of the beam axis; (b) typical ΔE–$E_{\rm tot}$ spectrum for the ^{9}Be + ^{9}Be reaction at $E_{\rm beam} = 45$ MeV and $\theta_{\rm lab} = 64°$, showing the ^{6}He band; and (c) projection of the selected band on $E_{\rm tot}$.

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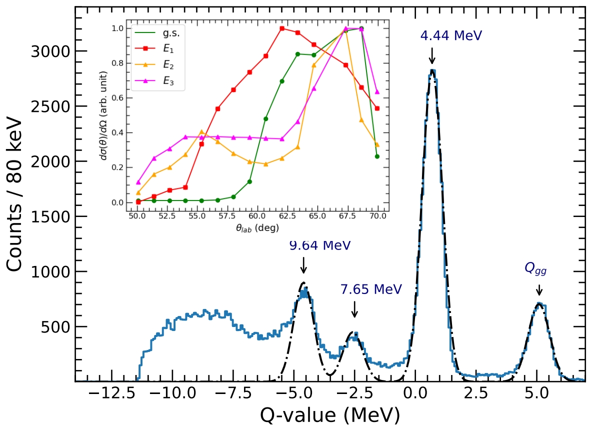

FIG. 2: Measured Q-value spectrum for the reaction ^{9}Be+^{9}Be $\rightarrow$ ^{6}He+^{12}C , extracted from the measured energy and angle of ^{6}He in the outgoing channel. The g.s. and different excited of ^{12}C are marked. The extracted preliminary angular distributions are shown in inset.

ΔE and E detectors. In Fig. 1(b) ^{6}He is clearly visible in the inclusive two-dimensional ΔE–$E_{\rm tot}$ spectrum for the ^{9}Be + ^{9}Be reaction at $E_{\rm beam}$ = 45 MeV and $\theta_{\rm lab}$ = 64°. The scattering angles (θ, ϕ) of the detected fragments with respect to the beam axis were determined from the hit positions recorded in the horizontal and vertical strips of the double-sided ΔE detectors.

III. ANALYSIS AND RESULT

In the ^{9}Be+^{9}Be reaction, ^{6}He could originate either from a direct ^{3}He-transfer reaction or from the break of the compound nucleus ^{18}O to ^{12}C and ^{6}He. Kinematically, these two reactions are indistinguishable and can only be probed by angular distribution. The reaction Q-value for this multinucleon transfer process is expressed as

$$Q = E_{^6\rm He} + E_{^{12}\rm C} - E_{\rm beam}$$

where $E_{^6\rm He}$ is the measured energy of the ^{6}He fragments obtained from the inclusive ΔE–E spectra, and $E_{^{12}\rm C}$ is reconstructed using the missing-mass technique. The extracted Q-value from the measured energy and angle of ^{6}He is shown in Fig. 2. The ground state (Q_{gg} = 5.10 MeV), as well as the excited states of ^{12}C at 4.44, 7.65, and 9.64 MeV, are clearly observed. The data were analyzed using a nonlinear least-squares minimization and curve-fitting procedure. For ^{6}He, the one-neutron separation energy is S_n = 1.71 MeV, and the first excited state at 1.79 MeV lies above the particle threshold. Hence, there is no contribution in the extracted spectrum due to the excitation of ^{6}He. The spectrum also contains contributions from the reactions ^{9}Be(^{9}Be, $\alpha\,^{6}$He)^{8}Be and ^{9}Be(^{9}Be, $\alpha\alpha\,^{6}$He)α. According to the semi-classical trajectory-matching model, the optimum Q-value is -5.5 MeV. In contrast, the Q value spectra exhibit a maximum yield at $Q = 0.66$ MeV, corresponding to the 4.44 MeV excited state of ^{12}C. Although, the observed energetics are not following the semi-classical model of direct reaction, the coupling of angular momentum is also need to be consider in the analysis. To disentangle the relative contributions of direct reactions and compound-nucleus processes, a quantum-mechanical calculation will be carried out to analyze the angular distribution. The extracted angular distribution of ^{6}He corresponding to the recoil ^{12}C in the ground state including a few excited states are shown in the inset of Fig. 2. Detailed analysis along with theoretical calculations will be presented.

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