Three body decay of Borromean ^{9}Be

S. K. Pandit[1],* A. Shrivastava[1,2], K. Mahata[1,2],
K. Ramachandran[1], V. V. Parkar[1,2], P. C. Rout[1,2],
S. Dhuri[1,2], T. Santhosh[1,2], Shilpi Gupta[1,2], and A. Kumar[1]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, India and*
[2]*Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094, India*

Introduction

Investigation of the 3-body decay mechanism of ^{9}Be nucleus is important not only from its fundamental aspect on cluster structure, but also as a promising tool in bridging the unstable mass gap at A=8 and producing carbon during nucleosynthesis [1, 2]. The ground state of ^{9}Be is bound by a binding energy of 1.57 MeV from α-α-n fragmentation. The nucleus ^{9}Be can be populated via direct and/or two step sequential mechanisms, e.g., $(\alpha+\alpha)^8$Be$_{g.s.}$+n, $(\alpha+\alpha)^8$Be$_{2^+}+n$ and $(\alpha+n)^5$He+α modes. Hence, it is very important to estimate the decay width of all possible decay channels of ^{9}Be for accurate estimation of the net rate of the burning of helium to carbon. In the present work we have aimed to resolve low lying $\frac{1}{2}^{\pm}$ and $\frac{5}{2}^{\pm}$ states, which are unbound and strongly overlapping due to their large widths.

Experimental Details

To investigate the decay mechanisms of various low lying unbound states, an experiment of α-α-n triple coincidence was carried out for the ^{9}Be+^{198}Pt system at the BARC-TIFR Pelletron-LINAC facility, Mumbai. The measurements were performed at beam energy of 45 MeV. An enriched ($\sim$95.7%) self-supporting $\sim$ 1.3 mg/cm^2 thick ^{198}Pt foil was used as target. Details of the experimental setup is available in Ref. [3]. Five segmented large area Si-telescopes of active area 5 x 5 cm^2 were used for the measurement of the energy and scattering angle of the outgoing α-particles. The telescopes were mounted at angles 40°, 70°, 115°, 145° and -55° in a compact scattering chamber of diameter 32 cm. All the five E-detectors were double sided with 16 strips allowing a maximum of 256 pixels. In view of better position information, which is very critical for momentum reconstruction, and large solid angle coverage with wide angular range, 15 liquid scintillator detectors (EJ-301) of 12.5 cm dia and 5 cm thick cylindrical shape coupled with photomultiplier tube were used to measure neutrons over an angular coverage of 30°-145°. Distance of the centre of the neutron detectors from the target is 72.5 cm [4]. One Si surface barrier detector of a thickness $\sim$ 300 μm was mounted at 20° in plane to monitor Rutherford scattering for absolute normalization purposes. The data were collected in event by event mode for two or higher fold coincidence in 120 ns time window from any strips out of all the E-detectors. The radio frequency signal from the pulsing system of the accelerator was logically ANDed with two fold coincidence of charged particles and used as reference to measure time of flight of the neutrons. The time calibration were carried out using precision time calibrator. The Si-detectors were calibrated using the known energies of α-particles from ^{239}Pu-^{241}Am and ^{229}Th sources.

Analysis and result

The energy loss information from ΔE and E detectors were used to identify the α-particles. Neutrons were discriminated from γ-rays using both pulse shape discrimination (PSD) and time of flight (TOF). A two-dimensional gate in the plot of TOF versus PSD was applied to obtain the neutron spectrum. Neutron energies were obtained by measuring the

*Electronic address: sanat@barc.gov.in

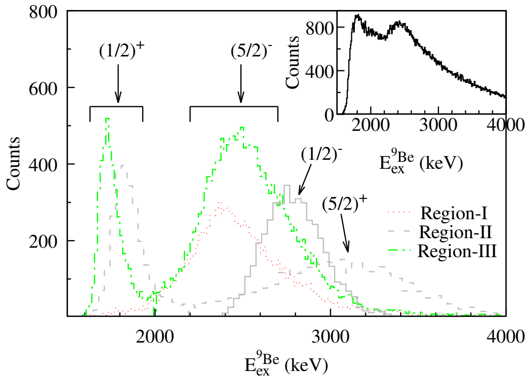

FIG. 1: Decomposed low lying $\frac{1}{2}^{\pm}$ and $\frac{5}{2}^{\pm}$ states using measured α-α-n triple coincidence and angular correlation technique (see text). In the inset reconstructed ^{9}Be excitation energy spectra from α-α-n triple coincidence is shown.

TOF of neutrons with respect to the pulsed beam. The measured energies (E_{α}^{1}, E_{α}^{2}, E_n) and scattering angles (θ_{α}^{1}, ϕ_{α}^{1}; θ_{α}^{2}, ϕ_{α}^{2}; θ_n, ϕ_n) were used to reconstruct the energy ($E_{^9\mathrm{Be}}$) and angle ($\theta_{^9\mathrm{Be}}$) of the scattered ^{9}Be prior to breakup. The energy (E^{*}) of the excited states of ^{9}Be were extracted using the energy conservation E^{*}=E_{α}^{1}+ E_{α}^{2}+E_n+E_{BU}^{th}-$E_{^9\mathrm{Be}}$, where, $E_{\mathrm{BU}}^{\mathrm{th}}$=1.57 MeV is the breakup threshold. The reconstructed ^{9}Be excitation energies are shown in the inset of Fig. 1. The excited states at 1.78 ($\frac{1}{2}^{+}$) and 2.43 ($\frac{5}{2}^{-}$) are observed in that excitation energy spectra. The good strength of the Coulomb excitation leads to a strong $E1$ transition, hence, a strong population of $\frac{1}{2}^{+}$ (1.78 MeV) state is observed unlike the observation of Ref.[5]. Although a clear identification of $\frac{1}{2}^{+}$ and $\frac{5}{2}^{-}$ states are achieved, other states are not resolved.

To resolve different states, the Dalitz-plot method was utilised. Different zones corresponding to different states and possible deay channels are identified in the simulated Dalitz plot. The simulation has been carried out using a four body Monte-Carlo kinematics. The exccitation enery spectra from the various region of the Dalitz plot are shown in the Fig. 1. Spectrum corresponding to the Region-I is the part of E^{*}=2.43 MeV ($\frac{5}{2}^{-}$) state exclusively decay via ^{8}Be$_{\mathrm{g.s.}}$+n mode. This fact is also verified from the measured relative energy spectra $E_{\mathrm{rel}}^{\alpha\alpha}$ found to be peak at 92 keV. However, Region-II is the part of decay from E^{*} = 1.78 MeV and 3.05 MeV via ^{8}Be$_{\mathrm{g.s.}}$+n mode only. Region-III is part of decay from E^{*} = 1.78 MeV and 2.43 MeV via ^{8}Be$_{2+}$+n mode. The breakup via α+^{5}He channel suppose to show a peak at 735 keV in $E_{\mathrm{rel}}^{\alpha n}$ spectra. No peak at 735 keV in $E_{\mathrm{rel}}^{\alpha n}$ spectra as well as very different shape in the measured and simulated Dalitz distribution assured that the breakup of E^{*} = 2.43 MeV and 3.05 MeV states via α+^{5}He mode is negligible. Using a gate of $E_{\mathrm{rel}}^{\alpha n}$=735±100 keV on Dalitz plot a region is identified, which corresponding to the excitation energy of ^{9}Be peaking at 2.78 MeV, marked as $\frac{1}{2}^{-}$ in the Fig. 1. It also confirms that $\frac{1}{2}^{-}$ (2.78 MeV) dominantly breaks via α+^{5}He channel. With this powerful method of kinematic Dalitz plot and triple coincidence measurement, low lying ($<$ 4 MeV) $\frac{1}{2}^{\pm}$ and $\frac{5}{2}^{\pm}$ states are resolved for the first time.

Acknowledgments

We acknowledge the accelerator staff for smooth running of the machine. We thank Mr. P. Patale for his help during experiment.

References

[1] S. E. Woosley and R. D. Hoffman, Astrophys. J. **395**, 202 (1992).
[2] C. W. Arnold, *et. al.*, Phys. Rev. C **85**, 044605 (2012).
[3] S. K. Pandit et al., Proc. of DAE Symp. on Nucl. Phys. **63**, 372 (2018).
[4] P. Rout, *et. al.*, JINST **13**, P01027 (2018).
[5] A. Pakou, *et. al.*, Nucl. Phys. A **1008**, 122155 (2021).