Three α-decays of Hoyle state of ^{12}C in ^{12}C + ^{12}C reaction

T. K. Rana[*1], C. Bhattacharya[1], S. Kundu[1], K. Banerjee[1], S. Bhattacharya[1], G. Mukherjee[1], T. K. Ghosh[1], J. K. Meena[1], P. Dhara[1], M. Biswas[1], H. Pai[1] K. Mahata[2], Suresh Kumar[2], K. Ramachandran[2], P. C. Rout[2], S. K. Pandit[2] V. Nanal[3] and R. G. Pillay[3]

[1]*Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata - 700 064, INDIA*
[2]*Bhabha Atomic Research Centre, Trombay, Mumbai - 400085, INDIA*
[3]*Tata Institute of Fundamental Research, Mumbai - 400085, INDIA*
** email: tapan@vecc.gov.in*

The low-lying resonance states of ^{12}C are being studied over many years both theoretically and experimentally for its astrophysical importance [1]. However, the energies and structures of the low-lying resonances below 10 MeV are still not well known. Recently, there is a lot of interest in the study of cluster states using resonance spectroscopy with special emphasis on the decay of second 0^+ excited state of ^{12}C at 7.65 MeV, the famous Hoyle state (through which ^{12}C is synthesized) [2]. Though extensive works have been reported to understand the nature of this Hoyle state, the study of structure of this state is still a subject of great interest [1-6]. This state is known to possess an extremely large radius (volume), which is sufficient for the α-particles to retain their quasi-free characteristics. Because of the bosonic nature of the spin zero ^{4}He nucleus, the state has been interpreted in terms of a Bose-Einstein condensate [4]. In this paper, we have studied the low lying resonance (Hoyle state) of ^{12}C and its decay mechanism i.e. direct or sequential decays into three α particles, in ^{12}C + ^{12}C reaction at low energy (~ 6 MeV/A).

The experiment was performed at the BARC-TIFR 14UD Pelletron, Mumbai, using 77 MeV ^{12}C ion beam on a ^{12}C target (self supported, thickness 90 μg/cm^2). Different fragments have been detected using a 3-element telescope [7]. The telescope consisted of a 50μm ΔE single-sided silicon strip detector (16 channels), 500μm ΔE/ E double-sided silicon strip detector (16 X 16 channels) and backed by four CsI(Tl) crystals (thickness 6 cm). The angular range in the laboratory covered by the telescope was from 18^o to 32^o. Typical angular resolution of each strip was ±0.4^o. All strips and the CsI(Tl) detectors were read out individually using standard readout electronics. A VME-based online data acquisition system was used for the collection of data on event-by-event basis.

Three-alpha coincidence events have been extracted from the data taken in inclusive mode. By reconstructing the kinematics of the particles after the decay of ^{12}C excited states, one can get the information about the decay mechanism, e.g. direct or sequential [5, 6]. The decay of states in ^{12}C* via. the intermediate, ^{8}Be, 0^+ level was analyzed by recording the emission patterns of alpha particles in the center-of-mass frame of the ^{12}C. The relative energies of these decay particles provide the information of the decay process by which each particle was produced; e. g. for sequential decay, if two of three α particles decay through ^{8}Be ground state then they must show the resonance at 92 keV of relative energy. Fig. 1 shows the relative energy spectrum of ^{8}Be constructed from two-alpha coincident events. The peak at 92 keV is due to the ground state (spin 0^+) of ^{8}Be and the parallel lines represent the gate used during the decay pattern analysis (direct or sequential decay) of ^{12}C states. Fig. 2 shows the excitation energy spectrum of ^{12}C reconstructed from the three α coincident event, which shows clearly the formation of Hoyle state at E_x ~ 7.65 MeV and the next excited state at E_x ~ 9.64 MeV. The decay of the Hoyle state (direct or sequential) has been studied using Dalitz plot. Fig. 3(a, b, c), which shows the relative energy spectra of any 2α particles detected in 3α coincident events of Hoyle state. The spectra in Fig. 3 were generated using the data which fall under ^{12}C (0^+) - ^{12}C in different states. The relative energy index 1 refers to most energetic α particle, 2 second most energetic and 3 the least energetic α particle. Fig. 3 (d) shows the Dalitz

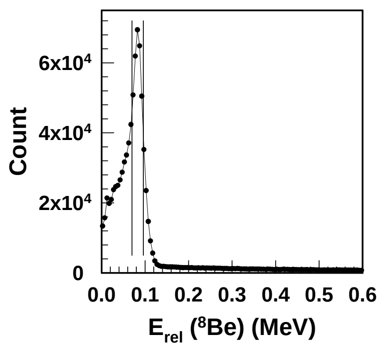

Fig. 1: Relative energy spectrum of ^{8}Be. Parallel lines are the gate used for the reconstruction of ^{12}C decay pattern.

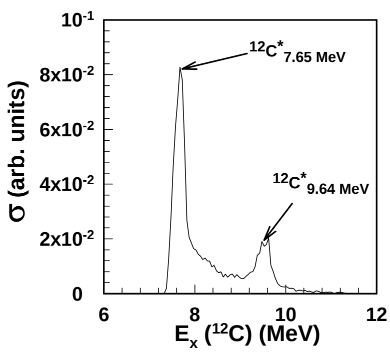

Fig. 2: Excitation energy spectrum of $^{12}C^*$.

plot for the decays of the 7.65 MeV state of ^{12}C. This was generated using the using the Dalitz parameters $\sqrt{3}(E_{rel}(23) - E_{rel}(12))/2$ and $(2E_{rel}(13) - E_{rel}(23) - E_{rel}(23))/2$, where $E_{rel}(ij)$ is the relative energy of the i^{th} and j^{th} particles. A similar analysis for the 7.65 MeV, 0^+ state was performed in Ref. [6]. The triangular locus in Fig. 3(d) shows that two of the α particles have a relative energy of 92 keV and preliminary analysis implies that the decay is mostly from sequential process through ^{8}Be ground state. The contribution from direct break up should be inside the circle inscribed by the triangle center at the centroid [6], which appears to be small.

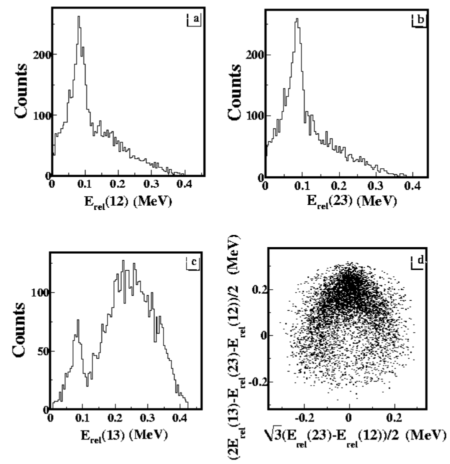

Fig. 3(a, b, c): Relative energy spectra for the three particles obtained in $^{12}C + ^{12}C$ reactions. Fig. 3 (d) shows the Dalitz plot for the decay pattern of the Hoyle state.

In summary, the cluster state (Hoyle state) formation and its decay mechanism has been studied in the reaction $^{12}C + ^{12}C$ and preliminary analysis shows that this state mostly decays sequentially through $^8Be + \alpha$ channels. Further analysis is in progress.

References:

[1] Fynbo HOU et al., Nature 433, (2005) 136.
[2] M. Freer et al., Phys. Rev. C 80, (2009) 041303 (R) and references therein.
[3] O. S. Kirsebom et al., Phys. Rev. C 81, (2010) 064313.
[4] A. Tohsaki, H. Horiuchi, P. Schuck, and G. Ropke., Phys. Rev. Lett. 87, (2001) 192501.
[5] Alvarez-Rodr´ıguez R, Jensen AS, Fedorov DV, Fynbo HOU and Garrido E., Rev. Lett. 99, (2007) 072503.
[6] M. Freer et al., Phys. Rev. C 49, (1994) 1751(R) and references therein.
[7] T. K. Rana et al., Phys. Rev C 78, (2008) 027602.