Search for the 2^+ state built on the Hoyle State

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The study of the Hoyle state in ^{12}C at 7.65 MeV is one of the topics of great interest. The 0^+_2 state plays a crucial role as a doorway state in the nucleosynthesis of carbon which in turn is the stepping stone to the formation of heavier nuclei in red giant stars. Currently the Hoyle state and its higher rotational member 2^+_2 are being studied in details by both theory and experiments. There are evidences for and against the existence of the higher rotational state. Investigations through different reaction routes have been carried out which indicates existence of a 2^+_2 state at ~10 MeV[1]. We report here a measurement to study the structural connection[2] between the 0^+_2 and 2^+_2 state through sequential decay of α & ^{8}Be from ^{24}Mg formed in ^{12}C+^{12}C fusion.

The measurement was performed at the Pelletron Linac facility (PLF), Mumbai using ^{12}C beams of energy ranging from 61 to 83 MeV. A self-supported 175 μg/cm^2 thick natural carbon target was used in the experiment. For detecting the charged particles, ΔE & E telescopes consist of silicon strip detectors (SSD) of thicknesses 50 & 1500 μm, respectively, were used. The ΔE & E SSDs size were 50x50 mm^2. The E detector had 16 vertical strips at the front & 16 horizontal strips at the back to provided the x,y position information of the interacting particle. The ΔE SSD has identical but only vertical strips at the front. The ΔE & E were set on a suitable mount at a relative separation of about 13 mm. Two such telescopes Tel#1 & Tel#2 were set at 15.9 cm from the target on two independent arms of a 1.5m diameter chamber. A surface barrier monitor detector was also set at 15° with respect to the beam. Here we will be presenting the preliminary data analysis for E(^{12}C)= 61, 65 & 71 MeV and for the detector angle settings Tel#1 at +36° & Tel#2 at –36°. The data were recorded in list mode in a VME based data acquisition system. The trigger used was generated with the condition that at least one event has occurred in each telescope. The SSDs were calibrated using a ^{229}Th α-source.

The data were analyzed for the sequential α & ^{8}Be decays of the compound nucleus formed which includes the reactions ^{12}C(^{12}C,^{8}Be)^{16}O* →α+^{12}C* and ^{12}C(^{12}C,α)^{20}Ne*→^{8}Be+^{12}C*. The data were filtered with appropriate timing and particle identification gates. As the ground state of ^{8}Be is a 92 keV unbound state it breaks up instantaneously (τ~10^{-16} s) into two alpha particles, it is identified by detecting the 2α in coincidence. To confirm that the 2 α are due to break up from a state of ^{8}Be, its relative energy was constructed employing the 2 α energies and their Cartesian coordinates. The analysis presented here is only for those events which have alpha multiplicity in Tel#1 as 2 (for ^{8}Be) and in Tel#2 as 1. A spectrum of the constructed relative energy of the two α detected at 65 MeV beam energy is shown in Fig.1. We observed here that almost all the events are in the 92 keV peak i.e., it is due to breakup of ^{8}Be$_{g.s.}$.

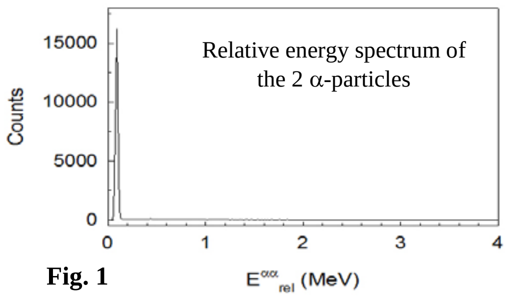

Fig. 1

Using the energy and position information of the three α-particles in the two telescopes the recoil energy of the ^{12}C was calculated and a total kinetic energy spectra of the exit channel is deduced which is shown in the Fig.2 for the three beam energies.

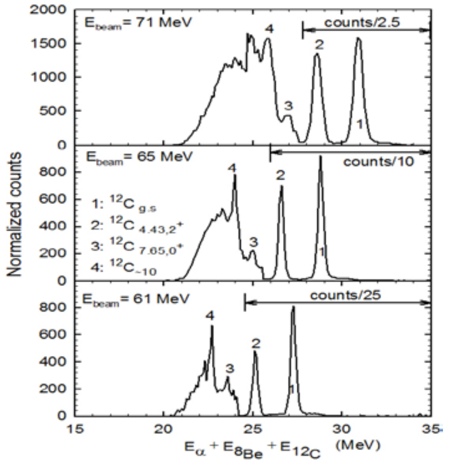

Fig. 2 Total kinetic energy spectra of the reaction

The counts at the three beam energies are normalized using integrated beam current. The observed prominent peaks in the spectra are corresponding to the g.s.; $4.43,2^+$; $7.65,0^+_2$ and a state at ~10 MeV in ^{12}C. We would like to point out here that it will be interesting to observe the cross section variation for the above four final residual states of ^{12}C with beam energies after computing the coincidence detection efficiency for the α-$^8Be_{g.s.}$ by a simulation program.

Assuming the first of the ^{8}Be & α sequential decay is ^{8}Be emission, its centre of mass energy spectra are deduced for each of the four peaks of Fig.2 for 65 MeV beam, and shown in Fig.3. This will address the ^{16}O intermediate states formed by ^{8}Be-decay of ^{24}Mg compound nucleus which ultimately α-decay to various final states of ^{12}C. A very interesting observation noted here that the 7.65 MeV Hoyle state and the ~10 MeV structure in ^{12}C are strongly fed through an intermediate ^{16}O state ~20 MeV. This excitation region of ^{16}O is known to have a highly deformed 4:1 axes ratio shape and likely to be a linear chain configuration [3].

The above observation indicates the structural overlap of the Hoyle state and the ~10 MeV state of ^{12}C as both are fed from the highly deformed alpha cluster state in ^{16}O. In conclusion this preliminary work support the observation of structural similarity of the 0^+_2 Hoyle state with the 2^+_2 state and possibly presenting the first experimental evidence that a known highly deformed state of ^{16}O decay preferentially to the Hoyle state and the 2^+_2 state at ~10 MeV which is conjectured as the higher member of the Hoyle state.

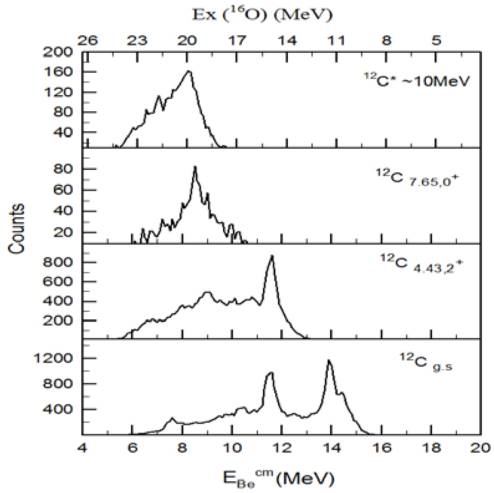

Fig. 3 First step ^{8}Be spectra to observe the intermediate ^{16}O states for the four final states of ^{12}C

Further analysis of data to bring out the correlation of the Hoyle state & its higher member to the ^{20}Ne intermediate state is underway and would be interesting to observe. For more statistics we would be also analyzing the data for first emission detected by Tel#2 & the subsequent decay detected by Tel#1. An angular correlation measurement is required to be carried out to study the spin parity of the states involved.

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