Fragment emission mechanism in $^{12,13}C + ^{12}C$ reactions

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Introduction:

Complex fragment emission mechanism in light heavy ion induced reactions ($A_{target} + A_{projectile} \leq 60$) at low bombarding energies but well above the Coulomb barrier has been studied quite extensively in many years [1]. The origin of these fragments extends from quasi-elastic, deep-inelastic transfer and orbiting to fusion - fission (FF) processes. The occurrence of fusion-fission (FF) and orbiting like processes have been observed experimentally in some light as well as medium heavy ion collisions [1–7]. For reactions involving α-clustered nuclei, e. g., $^{20}Ne + ^{12}C$, $^{24}Mg + ^{12}C$, $^{28}Si + ^{12}C$ etc., deserved special attention, where the observations of large enhancement in yield and/or resonance-like excitation function in a few outgoing channels have been indicative of a competitive role played by the deep-inelastic orbiting mechanism [3–6]. Both orbiting and fusion-fission processes occur on similar time scale. Therefore it is very difficult to differentiate the signatures of the two processes. Study of fragments emission mechanism is considered to be an important tool to study such entrance channel effects. Here we report our measurement of fragment emissions in ^{12}C on ^{12}C (α like) and ^{13}C on ^{12}C (non-α like) reactions at low energy.

Experimental details:

The experiment has been performed at Pelletron-Linac facility, Mumbai, using 80 MeV ^{12}C and 78.5 ^{13}C ion beams on ^{12}C target (~ 70 μg/cm^2). The emitted fragments have been detected using two telescopes, each consisting of 50μm ΔE single-sided silicon strip detector (SSSD), 1030μm E double-sided silicon strip detector (DSSD) and backed by four CSI(Tl) detectors, each of thickness 6 cm. Inclusive energy distributions for the various fragments ($3 \leq Z \leq 5$) have been measured in the angular range of 14^0 to 36^0. A VME-based online DAQ has been used for collection of data.

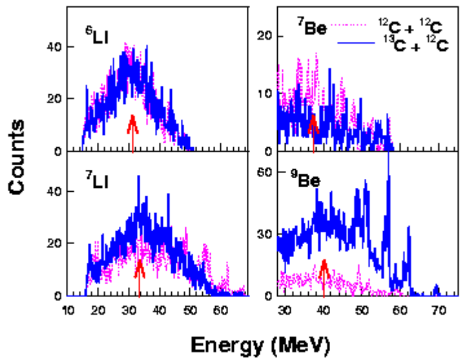

Fig. 1: Energy distribution isotopes of Li and Be fragments for the two reactions (see text).

Result and discussion:

Typical inclusive energy distributions ($\theta_{lab} = 14^0$) of different isotopes of Li and Be fragments obtained in the reactions $^{12}C + ^{12}C$ and $^{13}C + ^{12}C$ have been shown in Fig. 1 by dotted (pink) and solid (blue) lines, respectively. The counts in Y-axes are normalized to unity. The energy distributions are nearly Gaussian in shape (excluding the transfer channel), having the centroid at the expected kinetic energies for the fission fragments obtained from the Viola systematics corrected by the corresponding asymmetry factors [8], these are shown by arrows in Fig. 1. This suggests that fragments are emitted from fully energy relaxed composite as expected for both FF and orbiting processes. From the Fig. 1, it has been observed that the cross-section of formation of ^{9}Be in ^{13}C + ^{12}C is around 4 times more than of that in ^{12}C + ^{12}C reaction [9, 10].

Angular distributions of these isotopes have been obtained by integrating the respective normalized energy distributions under a fitted Gaussian with a mean value obtained from Viola systematics and have been shown in Fig. 2. The angular distributions of isotopes for both the fragments are found to follow ~ $1/\sin\theta_{c.m}$ dependence in center of mass frame (shown by red-solid lines in Fig. 2), which further conjecture the characteristics of completely equilibrated composite system [4-6].

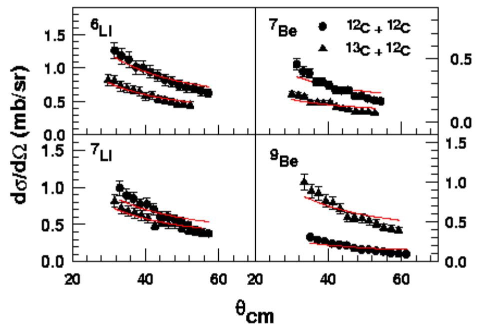

Fig. 2: Angular distribution of different isotopes of Li and Be for the two reactions (see text).

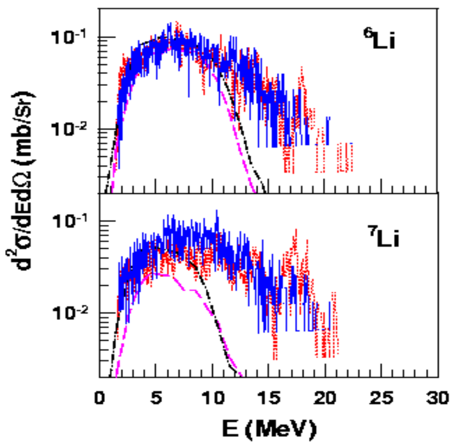

Fig.. 3: Center of mass energy spectra of ^{6,7}Li (dotted (red) line is for ^{12}C + ^{12}C (dash (pink) line: Gemini prediction), and solid (blue) line for ^{13}C + ^{12}C (dash-dot (black) line: Gemini prediction).

The center of mass energy spectra for the Li isotopes are shown in Fig. 3 with the corresponding theoretical predictions obtained using the statistical code GEMINI++ [11]. It is seen that the lower energy part of the spectra are well reproduced by the Gemini calculations. The higher energy part of the spectra, which are mainly due to transfer channels, and hence could not be predicted by the Gemini calculation.

In Conclusion, Fragments emission mechanism have been studied for ^{12}C (80 MeV) + ^{12}C and ^{13}C (78.5 MeV) + ^{12}C reactions. From the preliminary analysis, it has been observed that the energy distributions of isotopes of different fragments have centroid at the energy corresponding to the scission of deformed di-nuclear configuration and also the angular distributions of these isotopes are found to follow ~ $1/\sin\theta_{c.m}$ dependence in center of mass frame, which is the characteristics of a completely equilibrated, long-lived di-nuclear composite systems.. Further analysis is in progress to decipher the role of FF or orbiting type mechanism.

References

[1] S. J. Sanders et al., Phys. Rep. 311, 487 (1999) and references therein.

[2] C. Beck et al., Phys. Rev. C 49, 5 (1994).

[3] D. Shapira et al., Phys. Rev. Lett. 43, 1781 (1979).

[4] C. Bhattacharya et al., Phys. Rev. C 72, 021601(R) (2005).

[5] S. Kundu et al., Phys. Rev. C 78, 044601 (2008).

[6] S. Kundu et al., DAE Symp. On Nucl.Phys. 55, 326(2010).

[7] B. Shivakumar et al., Phys. Rev. C 35, 1730 (1987).

[8] V. E. Viola et al., Phys. Rev. C 31, 1550 (1985).

[9] C Bhattacharya et al., International DAE-BRNS Symp. on Nucl. Phys. 58, 530 (2013).

[10] T. K Rana et al., Int. J. Mod. Phys. E 20, 789 (2011).

[11] R. J. Charity, Phys. Rev. C 82, 014610 (2010).