Investigation of complex fragment emission mechanism at E/A ~ 20 MeV

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Introduction

The study of complex fragments (or IMF: $2<Z_{IMF}<A/2$) originating from heavy-ion collisions of different energies and masses have been a topic of interest in last few decades [1,2]. In these studies, the production mechanisms of IMFs have been associated to different processes viz. complete equilibrium processes like fusion evaporation (FE) or fusion-fission (FF) and / or non-equilibrium processes like quasi-elastic (QE), deep-inelastic (DI), incomplete fusion, and deep-inelastic orbiting processes. It has also been observed that with increase in beam energy, the production mechanism of the fragments shifts from equilibrium to non-equilibrium processes and sometimes it is overlap between the two, depending upon the beam energy and the target projectile combination. Although gross mechanism of complex fragment emission is now well understood at low energies, there remain some gaps at intermediate to high energies; especially the influence of entrance channel dynamics on the emission process. With the advent of sophisticated experimental tools, these gaps are getting filled through the measurement of isotopic yields of different fragments at different energy and mass domain. However, at intermediate energies, most of the studies have so far been done for heavier systems [projectile mass (A_p) + target mass (A_t) >100] and data for lower mass region is scarce. Therefore, an experiment has been designed to study the mechanisms involved in complex fragment emission for the reactions ^{14}N + ^{56}Fe and ^{20}Ne + ^{51}V forming composite nuclei ^{70,71}As*, at moderately high temperatures (T ~ 4.5 MeV).

Experimental details & Results

The experiment has been performed at K-500 super conducting cyclotron [3] at VECC, Kolkata with ^{14}N (270, 295 MeV) and ^{20}Ne (360, 440 MeV) ion beams on ^{56}Fe and ^{51}V targets, respectively. The beam energies have been chosen to populate the composites at similar temperatures. The reaction products have been detected using four ΔE-E telescopes [4] kept at both sides of the beam direction. The detailed descriptions of the telescopes and their central angles in laboratory (θ_{lab}) are given in Table 1.

Table 1: Telescope configuration

Telescope	Description	θ_{lab}
T1	Si strip (SSD ~55 μm + DSSD ~1030μm) + 4 CsI (Tl) (6 cm)	+60°
T2	Si strip (SSD ~55 μm + DSSD ~1508μm) + 4 CsI (Tl) (6 cm)	+30°
T3	Si strip (SSD ~55 μm + DSSD ~1510μm) + 4 CsI (Tl) (6 cm)	-30°
T4	Si strip (SSD ~52 μm + DSSD ~1038μm) + 4 CsI (Tl) (6 cm)	-60°

Fig. 1 shows a typical ΔE Vs. E particle identification spectrum obtained from T3, where fragments up to Z = 7 are found to be isotopically well separated, though Li isotopes show some fold-back at high energy tail parts. Therefore, the isotopes of ^{7,9}Be, ^{10,11}B and ^{11,12,13}C have been extracted for both the reactions and analysed.

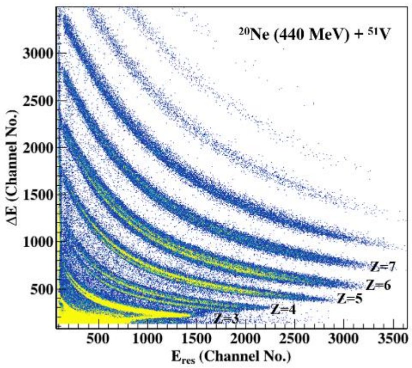

Fig. 1 2-D plot of particle identification from T3

The counts of energy spectra have been normalized with respect to the total incident beam, target thickness and detector solid angle. The energy spectra thus obtained for ^{14}N + ^{56}Fe (solid blue line) and ^{20}Ne + ^{51}V (dotted red line) reactions at a laboratory angle of ~23^{o} are shown in Fig. 2.

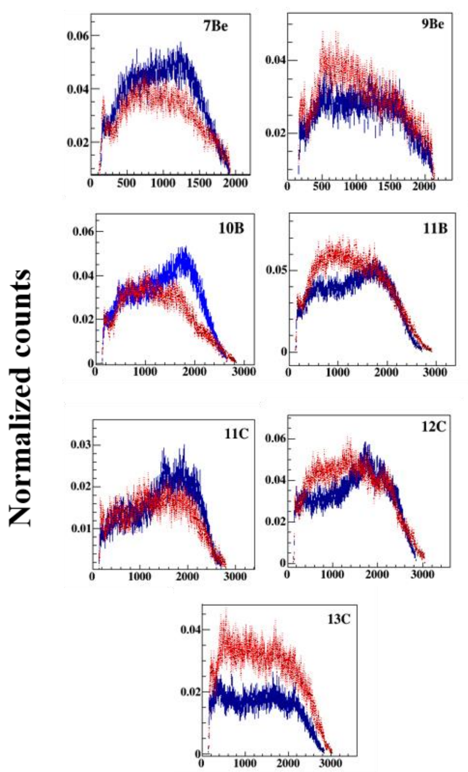

Fig. 2 Energy spectra of different isotopes (see text)

Discussion

It is observed from Fig. 2 that the overall distribution of the energies for different isotopes are similar for both the reactions. However, an extra peak like structure emerges at higher energy side for ^{14}N + ^{56}Fe reaction, especially for isotopes of B and C, which is somewhat absent in ^{20}Ne + ^{51}V reaction. The higher energy peak observed in B (Z = 5) and C (Z = 6) isotopes for ^{14}N + ^{56}Fe reaction may be due to the orbiting kind of contributions coming into play as these isotopes are very close to the projectile (Z = 7). Another interesting observation is that the relative yields of neutron rich isotopes are always higher for ^{20}Ne + ^{51}V reaction than the ^{14}N + ^{56}Fe reaction. This implies that N/Z equilibration has taken place inside the composites $^{70,71}As^{*}$ and the one excess neutron present in the composite ^{71}As plays its part to influence the isotopic yields.

Summary

Complex fragment emission has been studied for the reactions ^{14}N + ^{56}Fe and ^{20}Ne + ^{51}V at intermediate energies (E/A~18-22 MeV). Preliminary analyses reveal that the energy distributions of the fragments $^{7,9}Be$, $^{10,11}B$ and $^{11,12,13}C$ show subtle differences for the two reactions. Although, both the systems form same composites (with only 1n difference) at similar temperatures, there seems to be some entrance channel effect on the fragment energy distributions. Moreover, effect of N/Z equilibration is also evident from the normalized yields of the isotopes. Further analysis is in progress to extract the reaction mechanisms involved and estimate the relative cross sections of the fragments.

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References

[1] R. Charity, Nuclear Physics A **471** (1987).
[2] T. K. Rana et al., Phys. Rev. C **103**, 034614 (2021) and references therein.
[3] S. Kundu, et al., Nucl. Instrum. Methods Phys. Res. Sect. A **943**, 162411 (2019).
[4] T. K. Rana et al., Nucl. Instrum. Methods Phys. Res. Sect. A **1065**, 169530 (2024).