Fusion incompleteness in $^{14}N + ^{169}Tm$ system: Measurement of spin distributions

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Introduction

Heavy ion (HI) induced reactions have been a topic of great interest in nuclear physics from past decades [1]. At energies near and/or above the barrier the most dominating reaction process is complete fusion (CF), where projectile completely fused with the target nucleus and forms a highly excited compound nucleus (CN), which may de-excites via emission of particles followed by γ - rays. On the other hand, there is another reaction process termed as incomplete fusion (ICF). In this process, projectile breaks into two fragments in the vicinity of the target nucleus, one of the fragments fuses with the target nucleus and formed an excited composite system, while other moves in the forward direction with beam velocity [2-4]. The CN formed in ICF process have smaller mass, momentum and charge as compared to the CN formed in CF process, and also de-excite via emission of particles followed by γ - rays. The signature of ICF reaction first seen by Britt and Quinton [5] during the experimental studies of HIs (^{12}C, ^{14}N, ^{16}O) induced reactions with the targets ^{197}Au and ^{209}Bi at laboratory energies (E_{lab}) ≈ 7- 10 MeV/nucleon. Later, Inamura et. al. [6], disentangled CF and ICF reaction by using particle - γ - coincidence technique, where they observed the spin distribution of evaporation residues (ERs) populated through CF and ICF process behave differently.

In more qualitative way, the CF and ICF reactions were disentangled by the angular momentum (ℓ - values) imparted into the reaction system. Wilczynski et al. [7] in their sum rule model explained, if maximum angular momentum is less than that of critical angular momentum ($\ell_{max} < \ell_{crit}$), the nuclear reaction more probably leads to CF, on the other hand , for the case $\ell_{max} > \ell_{crit}$ the reaction may turns to breakup fusion or ICF. Several other models also proposed to explain the ICF reaction are Breakup fusion [8] and promptly emitted particle model [9] etc., but none of these model can explain ICF process below 10 MeV/nucleon.

In this manuscript, the spin distribution of ERs populated in $^{14}N + ^{169}Tm$ system at energy ≈ 5.86 MeV/nucleon has been measured, by implementing particle - γ - coincidence technique. It is found that the ERs populated through CF and ICF process behaves differently.

Experimental Details

The experiment using particle - γ - coincidence technique was performed at Inter-University Accelerator Centre, New Delhi, India for $^{14}N + ^{169}Tm$ system at projectile energy ≈ 5.86 MeV/nucleon. A self-supporting natural ^{169}Tm (abundance 100%) target foil of thickness ≈ 1.47 mg/cm^2 was prepared by rolling technique. Target foil was bombarded with ^{14}N ion (charge state 7^+) accelerated by 15UD pelletron accelerator. The particle - γ - coincidence events were recorded using Gamma Detector Array (GDA) along with Charge Particle Detector Array (CPDA). The GDA consists of 12 Compton suppressed High Purity Germanium detectors at angle 45˚, 99˚and 153˚ with respect to the beam direction at distance 18 cm from the target position. While, CPDA consists of 14 Phoswich detectors, arranged in two truncated hexagonal pyramids inside a small scattering chamber of diameter 14 cm. In the CPDA scattering chamber 7 charge particle detectors (CPDs) are placed on the top and 7 are placed in the bottom of the chamber. The CPDA is covering nearly 90% of total solid angle, while we have taken data from three annular rings: (i) forward angle (F) 10˚ - 60˚, (ii) sideways (S) 60˚ - 120˚ and (iii) backward angle 120˚ - 170˚. All CPDs were covered by Al - foil of appropriate thickness to subtract the scattered beam particle.

The direct α - particles (energy around ≈ 25 MeV) were detected by forward angles (F) CPDs. However, evaporated α - particles (energy around ≈ 20 MeV) were detected in backward angles (B) CPDs. The γ - ray spectra in coincidence with charge particle (Z = 1,2) emitted in forward, backward and sideways were recorded. The off-line data analysis has been done by software CANDLE [10].

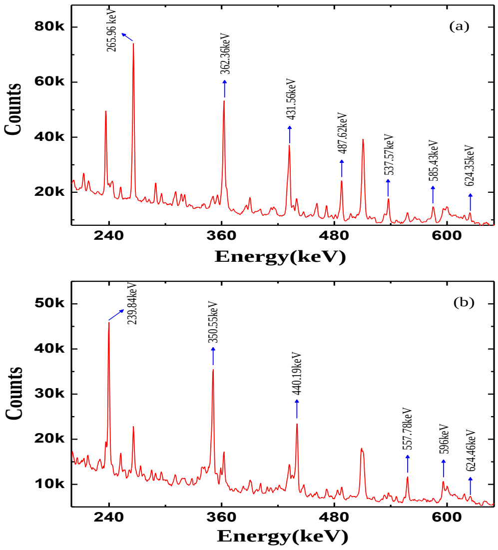

Fig. 1. γ - ray energy spectra observed from ^{14}N + ^{169}Tm system at projectile energy ≈ 5.86 MeV/nulean (a) singles and (b) alpha-forward-gated. Identified prompt γ - rays of ERs are marked.

Results and Discussion

In the present experiment, several ERs were identified, however, two of which are discussed here, data analysis of other ERs are still in progress and will be presented during the conference.

The measured spin distribution of ERs populated in CF and ICF reaction process are plotted in fig. 2 and 3, where normalised yield plotted as a function of observed spin (J_{obs}). The fig. 2 shows the spin distribution of ^{178}Os (5n), which is identified from singles spectra, it comes from the CF process.

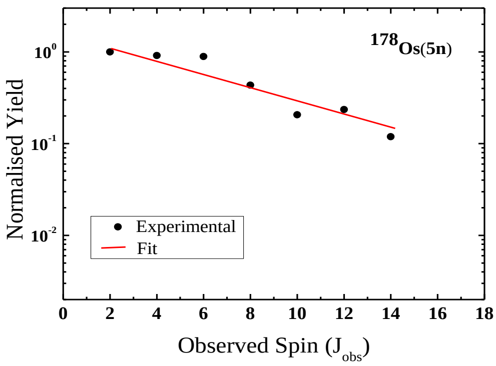

Fig. 2. Experimentally measured spin distribution of 5n channel (populated via CF process).

The fig. 3 shows the spin distribution of ^{176}W (α3n), which is identified from forward angles spectra (generated from coincidence between direct α - particles and prompt γ - rays), hence it may be populated via ICF process.

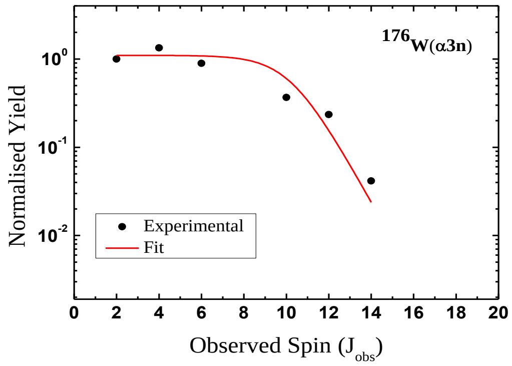

Fig. 3. Experimentally measured spin distribution of α3n channel (populated via ICF process).

It can be seen from the fig. 2, normalised yield falling exponentially with the spin states shows normal behaviour of de-excitation pattern of CN. However, fig. 3 indicates completely different de-excitation pattern of CN, it shows that normalised yield constant at lower spin states and falls sharply with the higher spin states.

The spin distribution of ERs populated via CF and ICF process behaves differently. It may be concluded that, in case of ICF lower spin states are not contributing (or hindered at lower spin states).

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