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Probing fusion inhibition in ^{19}F+^{197}Au via measurement of spin distribution

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Search for optimum conditions for synthesis of superheavy elements [1] has been a major impetus for the study of fusion between two heavy nuclei over the last several decades. Formation of a compound nucleus (CN), equilibrated in all degrees of freedom, following capture of the colliding system in a potential well is severely hindered because of the presence of fission-like processes. Further, survival of the CN, in the form of a heavy evaporation residue (ER), has an extremely low probability because fission becomes the dominant decay mode for very heavy CN. To understand the complex dynamics of fusion between two heavy nuclei, a host of experimental probes are employed. It becomes quite difficult to experimentally segregate the events leading to formation of the CN from the overwhelmingly dominant events arising out of non-compound fission-like processes, as the experimental observables in the two cases often have overlapping characteristics. Observation of ERs serves as the most definitive signature of formation of the CN.

Berriman *et al.* [2] conducted measurements of ER cross sections and fission fragment (FF) mass distributions for three reactions, *viz.*, ^{12}C+^{204}Pb, ^{19}F+^{197}Au and ^{30}Si+^{186}W, all leading to the same CN ^{216}Ra*. Signature of quasifission was found in the reactions involving heavier projectiles [2,3]. However, several other studies of the reactions ^{19}F+^{197}Au didn't find evidence of quasifission in this reaction and the experimental observables, *viz.*, FF angular [4] and mass [5] distributions and α-particle multiplicities [6] in coincidence with FFs, could be explained by the statistical model. The discrepancy between these studies call for further investigations.

Here we report an attempt to resolve the inconsistency in the decay dynamics of less-fissile systems like ^{19}F+^{197}Au by measuring ER-gated spin (ℓ) distributions. Results from such studies, especially the angular momenta that survive fission and fission-like processes to yield cold ERs in the ground state, might be useful in developing more reliable theoretical models to describe fusion between two massive nuclei.

The experiment was conducted using the HYbrid Recoil mass Analyzer (HYRA) [7] in gas-filled mode, coupled with the TIFR 4π spin spectrometer [8], at IUAC, New Delhi. A pulsed ^{19}F beam from the 15UD Pelletron, with a pulse separation of 2 μs, was bombarded onto a 250 μg/cm^2 thick ^{197}Au target. Beam energy ($E_{\rm lab}$) ranged from 86 to 112 MeV. ERs were separated from the more dominant background events by the HYRA and subsequently detected at its focal plane using a multi-wire proportional counter. To determine ℓ-distribution, the TIFR 4π spin spectrometer [8], comprising 32 NaI(Tl) scintillation detectors, arranged in a soccer-ball geometry around the HYRA target chamber, was employed. The spectrometer recorded the fold distributions of low-energy non-statistical γ-rays, emitted during decay of the ERs.

Raw γ-fold distribution was gated with the ERs detected at the focal plane, at each $E_{\rm lab}$, to obtain the true ER γ-fold distributions. The conversion of measured fold distribution to ℓ-distribution was carried out in two steps. First, the fold distribution was converted into the γ-multiplicity distribution and then the multiplicity distribution was transformed to the angular momentum distribution. The γ-multiplicity distribution was constructed using a detector response matrix, which was computed through a recursive algorithm [9]. The multiplicity distribution was assumed to have the form of a Fermi function with two adjustable parameters, *viz.*, the mean γ-multiplicity (M_0) and the diffuseness (ΔM) in the multiplicity distribution. These two free parameters were varied to achieve the best fit of the experimental γ-fold distribution.

The ℓ-distribution was obtained from the γ-multiplicity distribution, by the application of a generalized relation [10] between mean γ-multiplicity $\langle M_\gamma \rangle$ and mean angular momentum $\langle \ell_{\mathrm{CN}} \rangle$, according to the decay pattern of the CN. Based on the level scheme of dominant ERs, average spin carried away by each non-statistical γ-ray was estimated to be $\sim 1.7\hbar$. Further, moments of the multiplicity distribution were extracted. It was observed that the third moment, *i.e.*, skewness decreased gradually with increase in E_{lab}. This might be interpreted as reduced survival probability of higher ℓ at higher excitation energies. It is a challenge to determine experimentally whether non-survival of higher angular momenta is due to the entrance channel dynamics or has its origin in the statistical decay of the excited CN.

Dynamical model calculations, to describe evolution of the di-nuclear system, starting from the touching configuration, will complement these experimental results. Efforts to obtain a comprehensive theoretical understanding of the intricate reaction dynamics is ongoing.

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