Study of break-up fusion reaction in $^{16}O + ^{156}Gd$ system

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Introduction

The exploration of projectile break-up within heavy ion (HI) interactions has garnered significant interest, particularly for projectile energies ≈ 4-7 MeV/nucleon. In this energy region the two predominant reaction modes are complete fusion (CF) and incomplete fusion (ICF) processes. Intriguingly, contemporary measurements indicate that these processes begin to compete even at energies just beyond the Coulomb barrier [1-2].

In the case of CF, the entirety of nucleonic degrees of freedom comes into play as a result of the fusion of the entire mass of the projectile, bearing input angular momenta of $\lambda < \lambda_{crit}$. This culmination leads to the formation of an equilibrated compound nucleus (CN). On the contrary, within ICF reactions, the fusion of the entire projectile with the target nucleus faces hindrance for partial waves carrying angular momenta greater than λ_{crit}. To facilitate sustainable input angular momentum for fusion, the projectile might disintegrate into fragments, with one of these fragments subsequently fusing with the target nucleus, while the remaining fragment continues its forward trajectory.

The fragmentation or partial fusion of the projectile leads to a transfer of fractional linear momentum from the projectile to the target nucleus. This outcome consequently yields a composite nucleus with a diminished range within a stopping medium when compared to the composite nucleus formed in CF reactions. Thus, the measurement of forward recoil range distributions (FRRDs), resulting from partial linear momentum transfer, emerges as a compelling and definitive methodology to differentiate between the distinct CF and ICF components.

In FRRD measurements, the residues originating from CF and ICF processes correspond to different characteristic velocity distributions. An endeavour has been undertaken to study the break-up reactions via an analysis of forward recoil range distributions (FRRDs) exhibited by heavy residues populated through CF and/or ICF reaction routes.

Within the current investigation, FRRDs measurements for ^{16}O beam and ^{156}Gd target have been systematically studied at three distinct beam energies, $E_{lab} \approx 72$, 82 & 93 MeV.

Experimental details

An experiment was conducted at the Inter-University Accelerator Centre (IUAC) in New Delhi, India, utilizing the General Purpose Scattering Chamber (GPSC) facility. To ascertain FRRD measurements in the collision of ^{16}O-ion beam with ^{156}Gd target at energies ≈ 72, 82, and 93 MeV, the stack foil activation technique was employed, followed by offline analysis through γ-ray spectroscopy.

The ^{156}Gd targets and thin aluminum (Al) catcher foils were manufactured using a vacuum electro-deposition technique at the IUAC's Target Laboratory. The ^{156}Gd targets of thicknesses ≈ 0.59, 0.83, and 0.77 mg/cm²

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deposited on Al-backing foils of thicknesses ≈ 1.14, 1.20, and 0.98 mg/cm² were prepared rolling technique. The thin Al-catcher foils of thicknesses lying between ≈ 40-87 μg/cm^2 have been used in the present measurement. The three separate stack assemblies consisting of ^{156}Gd targets and Al-catcher foils were subjected to irradiation by a ^{16}O beam for durations of around 12 hours at ≈ 72 MeV, 13 hours at ≈ 82 MeV, and 15 hours at ≈ 93 MeV. The corresponding beam currents were ≈ 48, 60, and 15 nA.

To estimate the beam flux, the total charge collected at the Faraday cup situated behind the stack assembly of target and catcher was employed. Following the irradiation, the assembly containing the irradiated target and catcher was extracted from the scattering chamber. Subsequently, the induced activities within each Al-catcher foil were individually measured using a pre-calibrated, high-resolution HPGe detector with an active volume of 100 c.c. This detector was linked to a PC through CAMAC-based CANDLE software [3].

Results and Discussion

To gain insights into the reaction dynamics of ^{16}O + ^{156}Gd system, various entrance channel parameters ($Z_P Z_T$ and β_2^T) dependence of the ICF fraction has been studied in the present work.

The F_{ICF} values for different beams at projectile energy E_{lab}/V_b ≈ 1.35, along with various targets having $Z_P Z_T$ ranging from 350-550, has been plotted as in Fig. 1. Observing the figure, it is apparent that there is almost a linear increase in the F_{ICF} values across these various systems. This increase signifies that as the projectile approaches the target nucleus, the influence of Coulombic interaction becomes more pronounced. Consequently, the likelihood of projectile breakup rises followed by the fusion of one or more constituent fragments with the target nuclei. Hence, the increase in $Z_P Z_T$ corresponds to a strengthening of the Coulomb interaction, leading to a higher probability of projectile breakup.

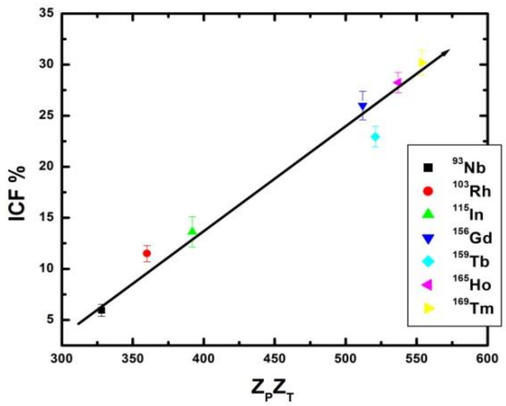

Fig. 1 A comparison of incomplete fusion function (F_{ICF}) deduced from the analysis of EF and FRRD measurement for ^{16}O beam with Coulomb-factor $Z_P Z_T$ for various targets at E_{lab}/V_{CB}= 1.35.

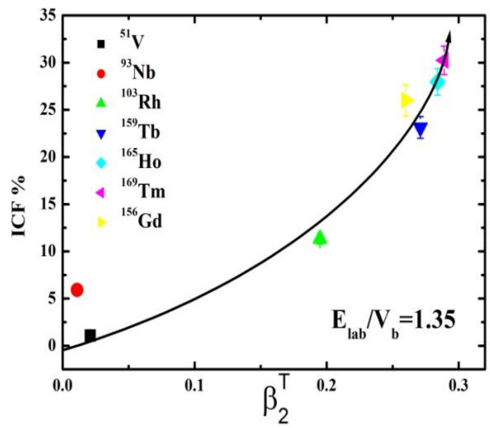

Fig. 2 The comparison of the incomplete fusion fraction F_{ICF} ^{16}O beam with deformation of target (β_2^T) for various targets at E_{lab}/V_{CB}= 1.35.

In this work an attempt has also been made to understand the effect of deformation of target (β_2^T) on the ICF dynamics. This parameter provides insights into how the orientation and shape of a nucleus impact these dynamics. We obtained β_2^T values for various targets from Ref. [4]. The determined F_{ICF}(%) values for our system, along with those for other systems, are illustrated in Fig 2. These plots clearly reveal an exponential increase in the ICF fraction with increasing β_2^T. Hence, suggesting the strong influence of entrance channel parameters on ^{16}O + ^{156}Gd reaction dynamics.

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