Investigation of complete and incomplete fusion by recoil range distribution measurements at ≈ 105 MeV

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Introduction

The incomplete fusion (ICF) reaction dynamics has been a topic of keen interest in nuclear physics for the past few decades, especially after the observation that these reactions start competing with Complete Fusion (CF) reactions just above the coulomb barrier [1-2]. A number of reaction channels open and a transfer of cluster of nucleons and angular momentum occur during the interaction of two heavy ions. The CF process in heavy ion reactions has been broadly studied for producing the nuclei at high angular momentum and high excitation energy which is not easily possible in light ion induced reactions. The projectile is assumed to break-up into fragments in the vicinity of the nuclear field of the target nucleus in ICF reaction process. To describe the mechanism of ICF reactions several models have been proposed, such as sum rule model [3], break-up fusion model [4]. The break-up fusion model of Udagawa and Tamura explained ICF process in terms of the break-up of projectile into fragments near the nuclear field of the target nucleus followed by fusion of one of the fragments with the target nucleus. To study the influence of various fusion components on ICF, Forward Recoil Range Distribution (FRRD) measurements for the $^{16}O + ^{89}Y$ system has been carried out at ≈ 105 MeV energy.

Experimental details

The experiment has been performed at Inter University Accelerator Centre (IUAC), New Delhi. Thin target foils of ^{89}Y having thickness ≈ 200μg /cm^2 have been prepared by using vacuum evaporation technique, on a thin Al-foil backing of thickness ≈ 1.92mg/cm^2. The thickness of target and Al-catcher foils were measured with the help of α-transmission method. The irradiation was done using $^{16}O^{7+}$ beam of ≈ 105 MeV energy in the general purpose scattering chamber (GPSC), which has an in-vacuum transfer facility (ITF). In the irradiation, stack of 14 Al-catcher thin foils (thickness ranging 93-144 μg/cm^2) were placed just behind the target, so that the residues populated via CF and/or ICF could be trapped at various catcher foil thicknesses. The target was bombarded with the projectile for ≈ 5 hours with a beam current of 27 nA as per the half-lives of the radioisotopes produced. The target ^{89}Y has been mounted in such a way that the Al backing first faces the beam so that the recoiling nucleus, if any, of very short range, does not stop in the target thickness itself. For the calculation of beam flux, the Faraday cup was placed behind the target-catcher assembly to collect the total charge. The induced γ-ray activity produced in each catcher foil was recorded using a pre-calibrated 100cc High-Purity Germanium detector (HPGe) coupled to a CAMAC based CANDLE software.

Results and Discussion

The forward recoil range distributions for a number of evaporation residues e.g. ^{101}Pd (p3n), ^{99}Pd (p5n), ^{100g}Rh (αn), ^{99m}Rh (α2n), ^{95g}Tc (2α2n), ^{94g}Tc (2α3n) etc. have been measured, in the present work. To obtain the differential recoil range distributions, the normalized yield have been plotted against the cumulative catcher thickness. In the heavy ion reactions, FRRD analysis provides an idea about the linear momentum transfer. As a representative case the FRRD of evaporation residues ^{95g}Tc and ^{94g}Tc are shown in Fig. 1 and Fig. 2, respectively.

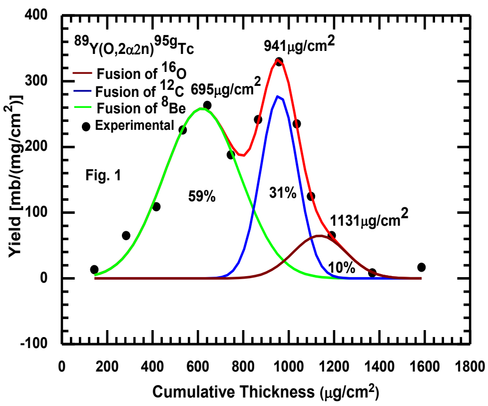
Table1. Experimentally measured most probable ranges R_p(expt) and theoretically estimated mean recoil ranges R_p(theo) in μg/cm^2 for residues produced via CF and/or ICF components in ^{16}O + ^{89}Y system at ≈ 105 MeV.

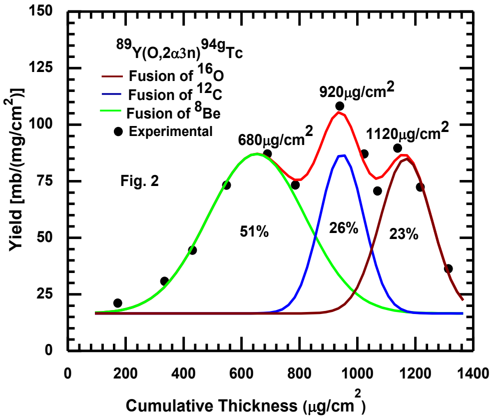
Residues	CF of ^{16}O		ICF of ^{16}O			
			Fusion of ^{12}C		Fusion of ^{8}Be	
	R_p (expt)	R_p (theo)	R_p (expt)	R_p (theo)	R_p (expt)	R_p (theo)
^{100g}Rh	1165	1171	960	969	—	—
^{99m}Rh	1290	1161	854	961	—	—
^{95g}Tc	1131	1136	941	942	695	707
^{94g}Tc	1120	1125	920	931	680	699

Table2. Measured relative contribution of CF and /or ICF components for residues produced in the ^{16}O + ^{89}Y system at ≈ 105 MeV.

Residues	CF of ^{16}O	ICF of ^{16}O	
		Fusion of ^{12}C	Fusion of ^{8}Be
^{100g}Rh	30%	70%	—
^{99m}Rh	43%	57%	—
^{95g}Tc	10%	31%	59%
^{94g}Tc	23%	26%	51%

In Fig.1, there are three peaks observed in the FRRD, which indicate the three linear momentum components in this distribution. Hence, in the production of ^{95g}Tc not only CF of ^{16}O but ICF of ^{12}C and ^{8}Be also takes place. The three peaks are obtained at depth of ≈ 695μg/cm^2, ≈ 941μg/cm^2 and ≈ 1131μg/cm^2 for the fusion of ^{8}Be, ^{12}C, and ^{16}O, respectively, with the target ^{89}Y, which are in agreement with the theoretical mean ranges obtained by the Stopping Power and Range Software (SRIM08) [5]. In Fig.2, the FRRD of evaporation residue ^{94g}Tc produced via (2α3n) emission channel shows three Gaussian peaks, corresponding to the most probable recoil ranges ≈680μg/cm^2, ≈920μg/cm^2 and ≈1120μg/cm^2 in the Al stopping medium. This indicates that the reaction ^{89}Y(^{16}O,2α3n)^{94g}Tc can be populated not only via CF but also through ICF process. The mean recoil ranges and the relative contributions of CF and / or ICF components for residues are shown in Table 1 and 2, respectively.





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