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SIGNATURE OF INCOMPLETE FUSION REACTION IN ^{20}NE + ^{159}TB SYSTEM: MEASUREMENT OF FORWARD RECOIL RANGE DISTRIBUTIONS (FRRDS)

Physics

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ABSTRACT

An attempt has been made to provide the qualitative information about linear momentum transfer (LMT) components associated with complete fusion (CF) and/or incomplete fusion (ICF) reaction, forward recoil range distributions (FRRDs) of six evaporation residues produced in the ^{20}Ne + ^{159}Tb system have been measured at ≈164 MeV energy and examined in the framework of the code SRIM. As such the normalized yields for these residues to obtain FRRDs have also been generated as a function of cumulative catcher thickness for each residue. The FRRD of the evaporation residues produced by complete fusion shows larger range than the residues produced by the incomplete fusion having shorter range. The recoil range distribution indicates significant contributions from incomplete fusion at 164 MeV for some alpha channels. Fraction of incomplete fusion probability increases with beam energy E/A ~ 8 MeV.

KEYWORDS

Nuclear reaction, Complete and Incomplete fusion reaction, forward recoil range distribution (FRRD)

INTRODUCTION

In the last couple of decades, study of the heavy ion induced reaction has raised the new interest especially about the complete fusion (CF) and Incomplete fusion (ICF) at energies near the vicinity of coulomb barrier [1-6]. For energy of the projectile increases to well above the coulomb barrier, projectile enters into the nuclear field of the target nucleus, varities of the nuclear reaction takes place. Predominant among them are CF and ICF. Heavy ion reaction mechanism can understand by several ways. One of them is impact parameter. At large value of the impact parameter, ions elastically or inelastically scattered by the coulomb field. Further, impact parameter is progressively reduced, direct reaction takes place associated few nucleon transfer from projectile to target and vice versa. If the impact parameter is still reduced deep inelastic (DIC) is playing an important role in heavy ion induced reaction. If impact parameter is further reduced, CF and ICF is the dominant mode of the reaction mechanism. It has been observed that at energies above the Coulomb barrier [7] CF and ICF are considered as the dominant reaction mechanisms. In the CF-reaction, nuclear field is too strong to hold all the nucleonic degree of the freedom with target nucleus, forms the excited composite system, which statistically decays by particle and/ or gamma emission. However in case of ICF, nuclear field is no longer hold to involve all the nucleonic degree of freedom of projectile and supposed to be break up into the fragments (for e.g; ^{20}Ne is break-up into ^{16}O and -particle; ^{8}Be and ^{12}C etc.) and one of the fragments fuses with the target nucleus while remnant part of the projectile moves as a spectator in the forward direction. This outgoing particle with large cross-section is called projectile like fragments (PLFs). The PLFs were first observed by Britt and Quinton [3] as the break up of projectile like, ^{12}C, ^{14}N and ^{16}O in an interaction of projectile with the surface of target nucleus. More experimental evidence for ICF was found by Inamura et al [5] by measurement of forward peaked alpha particles in coincidence with prompt gamma rays. The important features of the incomplete fusion reactions are (i) It is observed in case of low Z projectile (ii) outgoing particles have forward peaked angular distribution and energy spectrum peaked at beam velocity (iii) recoil range distribution of the evaporation residues show low range component suggesting incomplete momentum transfer (iv) spin distribution of the CF-product is distinctly different than that of the ICF-product. Our group has raised the step in this direction to study the FRRDs of ^{20}Ne-induced reactions on ^{159}Tb at energies well above the coulomb barrier to 8 MeV/nucleon. The CF and ICF-product have also been investigated by measuring the FRRDs of the residues produced in the heavy ion induced reactions. Infact, this technique is based on the linear momentum transferred from projectile to target nucleus. In case of the CF-reaction, complete momentum transferred from projectile to target nucleus, while in ICF-reaction, partial momentum transferred from projectile to target nucleus because partial mass of the projectile fused with target nucleus.

EXPERIMENTAL METHOD

In order to measure the recoil range distribution of the evaporation residues produced via CF and /or ICF in the collision of ^{20}Ne + ^{159}Tb at energy 164 MeV, we have carried out the experiment at Variable Energy Cyclotron Centre (VECC), Kolkata, India. The samples of target ^{159}Tb (natural abundance 99.9%) were rolled by rolling machine available at Saha Institute of Nuclear Physics (SINP), Kolkata in order to achieve the desired thickness of the targets. The Al-catcher foils of thickness 50-100 g/cm^2 were prepared by vacuum-evaporation technique. Thickness of the each target of ^{159}Tb of Al-catcher foils was determined by two methods [7]; (i) -transmission method (ii) Weighing method. The measured thickness of the ^{159}Tb samples were 1.23 and 1.31 mg/cm^2. In FRRD measurement, a thin terbium target foil of thickness 1.23 mg/cm^2 made by rolling machine was mounted in the specially designed irradiation chamber backed by stack of thin aluminium catcher foils so that the catcher stack immediately followed the Terbium foil. A stack comprises of fifteen thin aluminium catcher foils of thickness lying between 75-95 g/cm^2, prepared by using vacuum evaporation technique, was used to trap the recoiling residues. The target and catcher assembly were bombarded with ^{20}Ne ion-beam for about 9 hours and 40 min at ~ 34 nA beam current. The activity induced in each catcher foils were recorded by off-line ray spectrometer by using 100 cm^3 HPGe detector. To obtain the yield distribution as the function of cumulative thickness, the cross-section in each catcher was divided by its measured thickness [mb/(mg/cm2)]. The resulting yield has been plotted as the function of cumulative thickness to obtain the recoil range distribution.

FORWARD RECOIL RANGE DISTRIBUTION

The recoil range distribution has been measured for residues produced in the interaction of ^{20}Ne beam with ^{159}Tb at energy at 165 MeV. FRRD measurement gives an idea of linear momentum transfer from projectile to target. The FRRD of six evaporation residues ^{174}W, ^{175}Ta, ^{173}Ta, ^{172}Ta, ^{164}Yb and ^{165}Tm have been measured in the present measurement. The FRRD of ER ^{174}W is shown in Fig. 1(a). The evaporation residue ^{174}W is produced by emission of 1 proton and 4 neutrons from the composite system ^{179}Re*, populated in the fusion of ^{20}Ne with ^{159}Tb. As it can be observed from the Fig. 1(a) that FRRD of ^{174}W shows single Gaussian peak at cumulative thickness ~ 985 μg/cm^2, corresponding to full momentum transfer from projectile to target. The experimentally measured most probable range of ^{174}W reaction product is found to be in good agreement with theoretically calculated range ~ 970 μg/cm^2, using code SRIM08 [8], which clearly shows that the product ^{174}W is formed via CF of ^{20}Ne with ^{159}Tb. The measured FRRD of the residues ^{175}Ta and ^{173}Ta, populated in break-up α-emission channel, are shown in Figs.1 (b)-(c). One may observe from these figures that these residues give single Gaussian recoil peak at cumulative catcher thickness ~ 924 μg/cm^2 and 913 μg/cm^2 respectively, which corresponds to the residues produced predominantly through ICF of projectile ^{20}Ne i.e., in fusion of the fragment ^{16}O (produced in the break-up of the projectile ^{20}Ne into ^{16}O and ^{4}He (α)) with target nucleus ^{159}Tb, forming incompletely fused composite system ^{175}Ta* in the excited state. In its de-excitation by 2 neutrons, residue ^{173}Ta is produced. However, un-fused 'fast' α-particle moves in forward direction. As such, production of these residues are observed in ICF of the projectile and a partial linear momentum

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transfer (LMT) takes from projectile to the target. Most probable recoil peaks at measured cumulative catcher thicknesses for residues ^{175}Ta and ^{173}Ta are in agreement with theoretically calculated ranges. The FRRD of residue ^{172}Ta shows two peaks structure as shown in Fig. 1 (d). As can be observed from this figure, the residues ^{172}Ta may be formed via CF as well ICF of ^{20}Ne with ^{159}Tb. In case of CF, the composite system ^{179}Re* is formed, which may decay via statistical emission of 1 α-particle and 3 neutrons leaving behind the residue ^{172}Ta. This residue may also be populated via ICF of the projectile, where as the fragment ^{16}O (in the projectile break-up) fuses with target nucleus ^{159}Tb, forming an incompletely composite system ^{175}Ta*, which may decay by the emission of 3 neutrons leaving behind the above residue. In the CF of the projectile, full linear momentum transfer (LMT) takes place and peak is observed at cumulative catcher thickness ~ 1009 μg/cm^2, while in ICF of the projectile, since a partial linear momentum is transferred, the peak is observed at a smaller distance in the catcher medium, ~ 904 μg/cm^2. The measured mean recoil ranges are in close agreement with the theoretical ranges, ~970 and ~ 916 μg/cm^2 respectively, calculated using code SRIM08 [8].

In case of 2α-emission product ^{164}Yb, forward RRD shows a composite structure which is resolved to get two recoil peaks at cumulative thicknesses ~ 907 and ~ 683 μg/cm^2 as displayed in Fig.2. The peak observed at higher range corresponds to the ICF of ^{20}Ne i.e., fusion of fragment ^{16}O [if ^{20}Ne breaks-up into ^{16}O and ^{4}He ()] with ^{159}Tb. The second recoil peak observed at lower range corresponds to ICF of the projectile in the fusion of

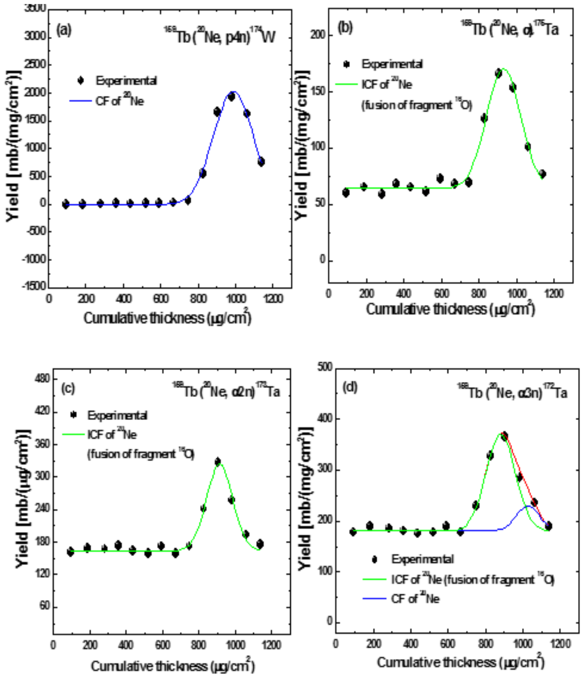

Fig. 1: The experimentally measured FRRDs of evaporation residues ^{174}W, ^{175}Ta, ^{173}Ta and ^{172}Ta, produced via CF and/or ICF, for ^{20}Ne + ^{159}Tb system at energy, E ~ 164 MeV.

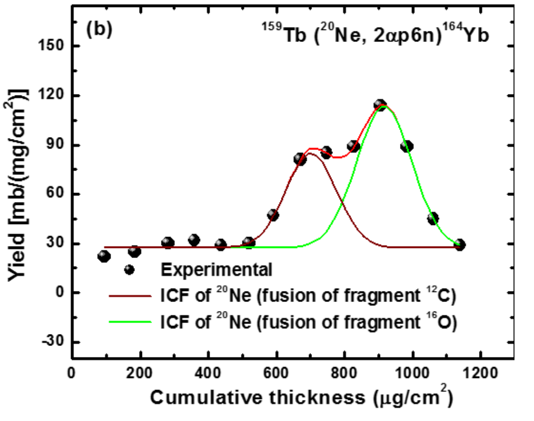

Fig.2: The experimentally measured FRRD of ER ^{164}Yb produced via ICF for ^{20}Ne + ^{159}Tb system at energy, E~164 MeV.

fragment ^{12}C [if ^{20}Ne breaks-up into ^{12}C and ^{8}Be (2)] with the target. It is obvious that the partial linear momentum transfer (LMT) in fusion of the fragment ^{16}O will be more than in fusion of fragment ^{12}C. The peak corresponding to expected mean recoil range (~970 μg/cm^2) of CF channel has not been observed. The absence of the CF channel peak indicates that the residue ^{164}Yb predominantly produced through the ICF of ^{20}Ne. As such, the recoil profiles of the residues ^{165} Tm in Al-catchers, produced in 32n reaction channels also show three recoil Gaussian peaks, associated with three partial linear momentum transfer (LMT) components at three cumulative catcher thicknesses. In residue ^{165}Tm, as shown in Fig. 3, three well resolved peaks are observed at ~906 , ~663 and ~448 μg/cm^2. As discussed above, these peaks are associated with ICF of projectile ^{20}Ne (i.e., in the fusion of fragment ^{16}O, fusion of fragment ^{12}C and fusion of fragment ^{8}Be respectively) with the target ^{159}Tb.

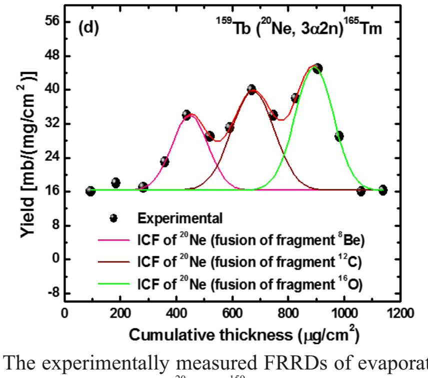

Fig.3: The experimentally measured FRRDs of evaporation residues ^{165}Tm produced via ICF, for ^{20}Ne + ^{159}Tb system at energy, E~164 MeV.

Observation of no peak at CF recoil range, indicates that no full linear transfer components are observed in these residues and hence these are predominantly produced through ICF process. Experimentally measured most probable ranges $(\exp)_p R$ along with)$(theoR_p$ evaluated from code SRIM08, for CF and ICF components for each residues in the ^{20}Ne + ^{159}Tb system at ~164 MeV are listed in Table 2.

Residues	[μg/cm2] CF of 20Ne	**[μg/cm2]CF of 20Ne**	**[μg/cm2] ICF of 16O**	**[μg/cm2] ICF of 16O**	**[μg/cm2] ICF of 12C**	**[μg/cm2] ICF of 12C**	**[μg/cm2] ICF of 8Be**	**[μg/cm2] ICF of 8Be**
174W (p4n)	985 ± 105	970						
175Ta ()	---		924 ± 90	916				
173Ta (2n)	---		913 ± 70	916				
172Ta (3n)	1009 ± 75	970	904 ± 60	916				
164Yb (2p6n)	---		907 ± 75	916	683 ± 80	651		
165Tm (32n)	---		906 ± 68	916	663 ± 76	651	448 ± 64	443

Table 2: The experimentally measured forward recoil ranges $R_p(\exp)$ deduced from RRD curves, and theoretically calculated most probable ranges$R_p(theo)$for CF and /or ICF component using range energy relation for the reaction products produced in the interaction of 20Ne with 159Tb at energy, E~164 MeV.

CONCLUSIVE REMARKS

In order to study the qualitative information regarding ICF reaction dynamics at projectile energy ~ 8 MeV/ nucleon, the FRRDs of six ERs; 174W, 175Ta, 173Ta, 172Ta, 164Yb and 165Tm populated in 20Ne + 159Tb system at energy, E ~164 MeV have been measured. The partial linear momentum transfer (LMT) component associated with break-up of the projectile viz; 20Ne into 16O + 4He (α) and/or 12C + 8Be (2α) and /or 8Be + 12C (3α) have been observed. The measurement and analysis of the FRRD of evaporation residues strongly revealed that significant contributions coming form partial linear momentum transfer of projectile associated with incomplete fusion reaction dynamics in several α-emission products. In general, it has been found that the residues are not only populated via CF but ICF also plays an important role at respective projectile energies. An attempt has also been made to validate the experimentally measured forward recoil ranges $(\exp)_p R$ deduced from fitting of experimentally RRD data points. The experimentally measured most probable recoil ranges have been compared with theoretically calculated most probable ranges $)(theoR_p$ for CF and /or ICF component, using range-energy relation for the reaction products produced in the interaction of 20Ne with 159Tb are found to be in good agreement at respective projectile energies.

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