P: ISSN NO.: 2394-0344 RNI No.UPBIL/2016/67980 VOL-3* ISSUE-4* July- 2018
E: ISSN NO.: 2455-0817 Remarking An Analisation

Incomplete Fusion Reaction in ^{20}Ne + ^{159}Tb System

Abstract

This paper presents to study more complex and interesting phenomenon of incomplete fusion (ICF) reactions induced by ^{20}Ne on ^{159}Tb have been measured at several beam energies range of 4.3-8.2 MeV/A by using catcher foil technique followed by the gamma-ray spectrometery. The measured excitation functions have been compared with statistical model based computer code PACE-2. The alpha emission products shows higher cross-section than that predicted by the complete fusion product. This enhancement in the measured cross-section is attributed to the fact that these residues are formed not only by complete fusion but also through the incomplete fusion. The excitation functions measurements indicate significant contributions from incomplete fusion at 4.3 MeV/A for some alpha channel. To the best of our knowledge, these measurements have been reported for first time.

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Introduction

In the last couple of years, 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[1-4]. 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 for e.g; elastic, inelastic scattering (CF & ICF), transfer reaction, deep inelastic collision (DIC) and direct reaction (DR) because of the complex nature of the ions. Predominant among them are CF and ICF. Heavy ion reaction mechanism can under stood by several ways. One way is based on 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 HI-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 [5] 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 of large flux with less or undeflected velocity as that of the projectile. This outgoing particle with large cross-section is called projectile like fragments (PLFs). The PLFs were first observed by Britt and Quinton[6] 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 [7] 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 [8] (iii) recoil range distribution of the evaporation residues show low range component suggesting incomplete momentum transfer (iv) ICF associated with mass-asymmetric system (v) spin distribution of the CF-product is distinctly different than that of the ICF-product. By measuring the excitation function in heavy ion induced reactions have indicated that ICF is an important reaction mechanism at moderate excitation energy.

Some of the features of the ICF-reaction dynamics can be understood on the basis of the several dynamical models viz; SUMRULE model [9], BREAK-UP FUSION (BUF) model [10], PROMPTLY EMITTED PARTICLES (PEPs) model[11], HYBRID model [12] etc; have been proposed. The SUMRULE model [9] of Wilczynski et al describes the ICF reactions occur in the peripheral interactions and localized in the angular momentum space above the critical angular momentum of the complete fusion. The BUF-model of Udgawa and Tamura[10] is based on the distorted wave Born approximation (DWBA), where projectile is supposed to break-up in the field of the target nucleus. One of the fragments of the projectile is assumed to fuse with target nucleus and remaining fragments moves with less or unchanged velocity in the forward direction with large flux. In PEP models[11], particles are transferred from projectile to target nucleus is assumed to accelerate in the nuclear field of the target nucleus and gets accelerated. Moreover, in the hybrid model of Blann et al[12] and Fermi-jet model[13-15] have also been describes features of ICF reactions. With this view, above existing models qualitatively explain the experimental data at energies $\geq$ 10 MeV/ nucleon. In the last decade, several report appeared to show that ICF-reaction mechanism play an important role even at low energies around 5-7 MeV/ nucleon[16-20]. At energies 6 MeV/ nucleon, Parker et al [21] observed the fast α-particle in the low Z-heavy ion interaction on ^{51}V. Morngston et al[22-23] observed the velocity spectra of the evaporation residues in the bombardment of ^{40}Ar with boron and carbon targets and also showed that the ICF reaction cross-section significantly contribute to the total reaction cross-section for mass-asymmetric system to the mass symmetric system. Furthermore, ICF reaction is assumed to produce the residues in the high spin states even at low bombarding energy of the projectile[24-25].

Aim of The Study

The aim of this paper is to study heavy ion induced reaction especially complete fusion (CF) and incomplete fusion (ICF) dynamics in ^{20}Ne + ^{159}Tb system at energy range 87-164 MeV. We have measured the excitation function of the evaporation residues produced in the above reaction and compared with statistical model computer code PACE-2 which gives the signature of CF and ICF reaction dynamics energy range 87-164 MeV. In this measurement, catcher foil technique has been employed followed by γ-ray spectroscopy.

Review of The Literature

Among the nuclear physicist, there has been resurgent interest to study the heavy ion induced reaction mechanism from couple of years. If projectile energy well above the barrier height, varieties of nuclear reaction takes place like Direct reaction, Transfer reaction, Complete Fusion (CF) and Incomplete Fusion (ICF), Deep inelastic collision (DIC), Pre-equilibrium reaction etc. are playing an important. Exiting data in literature [26] predict that projectile energy near and/or well above the fusion barrier; CF and ICF are most dominating processes. These two reaction dynamics were first reported by R. Kaufmann and R. Wolfgang[27] in the year 1961. Subsequently, these reactions were observed by Britt and Quinton [6] by the bombardment of ^{12}C, ^{14}N and ^{16}O projectiles at energies near and well above the barrier. Later on, ICF-reactions were first observed by T. Inamura et al[7] by the measurement of forward peaked α-particle in coincidence with prompt γ-rays in ^{14}N + ^{159}Tb system at 95 MeV-beam energy. Earlier studies of ICF were concentrated at energies above 10 MeV/ nucleon. Some of the important features originated from the literature regarding the ICF dynamics are: (a) Its probability is more in low Z projectile (Z<10) and high Z-target; (b) Incomplete fusion reaction starts competing with complete fusion (CF) reaction just above the coulomb barrier (c) Forwarded projected range show shorter range in the stopping medium as a result of fractional momentum transfer takes place from projectile to target [28]; (d) Projectile like fragments (PLFs) are mainly concentrated in the forward cone and its peak in energy spectrum at projectile velocity[6]; (e) spin distribution of the residues populated via incomplete fusion are distinctly different from that of CF process[29]; (f) ICF probability is more in mass asymmetric system than mass symmetric system [30].

Experimental Method

In order to measure the EFs of six evaporation residues produced via CF and /or ICF in the collision of ^{20}Ne + ^{159}Tb in the wide energy range 4.3-8.2 MeV/A, we have carried out the experiment at Variable Energy Cyclotron Centre (VECC), Kolkata, India. In this experiment, we have used the two stacks of the Terbium (^{159}Tb) samples; (i) stack-I carries the six ^{159}Tb-target foils each having thickness is around 1.23 mg/cm^2; (ii) second stack consist of seven target foils of ^{159}Tb having thickness around 1.31 mg/cm^2. The samples of the monoisotopic 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 $\approx$ 50-100 μg/cm^2 were prepared by vacuum-evaporation technique. Thickness of the each target of ^{159}Tb of Al-catcher foils was determined by α-transmission method in which energy lost by 5.485 MeV α- particle of ^{241}Am-source, while passing through the sample. The measured thickness of the ^{159}Tb samples were 1.23 and 1.31 mg/cm^2. Two stacks of ^{159}Tb-samples accompanied by six and seven samples were irradiated by $^{20}Ne^{+6}$ at energy 164 and 130 MeV. The beam energy for each foil is the average of incoming and outgoing beam energy for that target foil. The beam currents for stack-I and stack-II were 50 and 33nA. Keeping the view of half-life, the irradiations carried out for stack-I and stack-II were 6h: 30m and 4h. Thus, the irradiation of the targets were covered the wide range of energy 165-87 MeV respectively. The ^{159}Tb-target backed by Al- degraders of thickness ~1.2 mg/cm^2 were placed normal to the beam direction so that recoiling nuclei were trapped in the Al- degraders. We have arranged the experiment in such a way, to minimize the time lapsed between stop of irradiation and start of counting. The total charge collected at the faraday cup was used to measure the beam-flux.

Production Cross-Section of Evaporation Residues

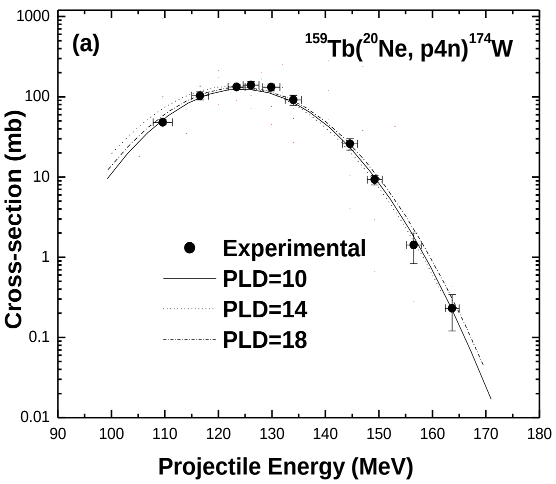
The measured cross-section of the evaporation residues produced via CF and /or ICF have been calculated by using the following formula;

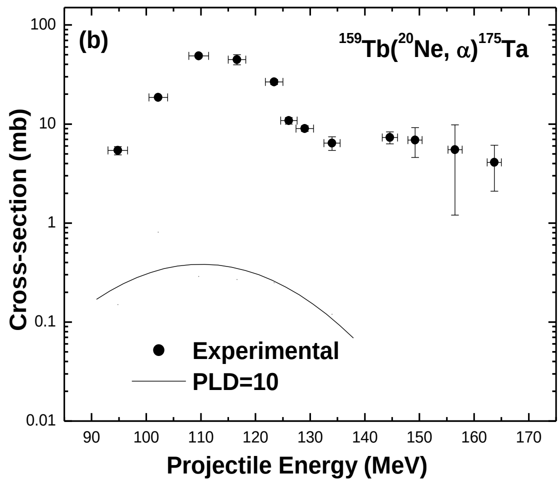
$$\sigma_r = \frac{A\lambda \exp(\lambda t_2)}{N_0 \theta\phi\varepsilon_G K[1-\exp(-\lambda t_1)][1-\exp(1-\exp(-\lambda t_3)]}$$

Where symbols having their usual meaning[1-2]. The excitation functions for the ten reactions have been measured in the collision of ^{20}Ne + ^{159}Tb in the wide energy range 4.3-8.2 MeV/A by using recoil catcher technique followed by the γ-ray spectrometry. One of the main advantages of this technique is to measure the cross-sections for the large number of the reactions in a single irradiation. The EFs for the measured reaction have been compared with the statistical model computer code PACE-2 [31]. The theoretical estimates of the reaction cross-section were made by PACE-2. It is based on the statistical model approach and uses the Monte-Carlo simulation technique for the de-excitation of the compound nucleus. The complete fusion cross-sections are calculated using the Bass formula. In the present calculations of the excitation functions for evaporation residues, the level density parameter is given by a = A/PLD, where A is the mass of the compound nucleus and PLD is the free parameter. The value of the PLD may be varied to match the experimental data. The effect of the variation of the level density parameter (PLD) on the calculated excitation function for ^{159}Tb (^{20}Ne, p4n)^{174} W reaction is shown in Fig. 1(a). It is evident from Fig. 1(a), value of PLD=10 is found to reproduce the measured excitation function. The residue ^{174}W (p4n) is produced via CF of the ^{20}Ne with ^{159}Tb-target forming the composite nucleus ^{179}Re, which decays by 1p and 4n, where 'p' and 'n' stands for proton and neutron. While, tantalum isotopes i.e; $^{172, 173, 174, 175}$Ta produced via α3n, α2n, α1n and α0n-channel; and residue ^{173}Hf is produced via αpn-channel is shown in Figs. 1 (a-f). It can be seen from Figs. that calculated cross-section underestimated the measured cross-section in a order of magnitude, which clearly revealed that these residues produced through CF and /or ICF reaction mechanism. In case of the CF, all the nucleonic degree of freedom of the projectile is fuses with target nucleus, forming the composite nucleus ^{179}Re, which may decays via 3n, 2n, 1n, and on, for $^{172, 173, 174, 175}$Ta along with α-particle. The same tatalum isotopes are also formed via ICF; it can be explained by the break-up of ^{20}Ne into fragments (α + ^{16} O) in the field the target nucleus. One of the fragments ^{16}O fuses with target nucleus ^{159}Tb forming the composite system ^{175}Ta*, which decays via 3n, 2n, 1n and 0n for $^{172, 173, 174, 175}$Ta. Hence, these Ta-isotopes is produced through CF and /or ICF. The enhancement in the measured cross-section comes form ICF-reaction of the type;

^{20}Ne (^{16} O + α) + ^{159}Tb ⇒ ^{175}Ta* + α (α as spectator) (1)

Further, in case of the reaction product ^{173}Hf may be formed via ICF of the ^{20}Ne with ^{159}Tb followed by the equitation (1). It may be explained by the break-up of the ^{20}Ne into fragments (α + ^{16} O) in the field the target nucleus. One of the fragments ^{16}O fuses with target nucleus ^{159}Tb forming the composite system ^{175}Ta*, which decays via 1p 1n and unfused part of the projectile goes in the forward direction without any interaction with target nucleus. The measured cross-section for this reaction product is mainly through the ICF-reaction mechanism.





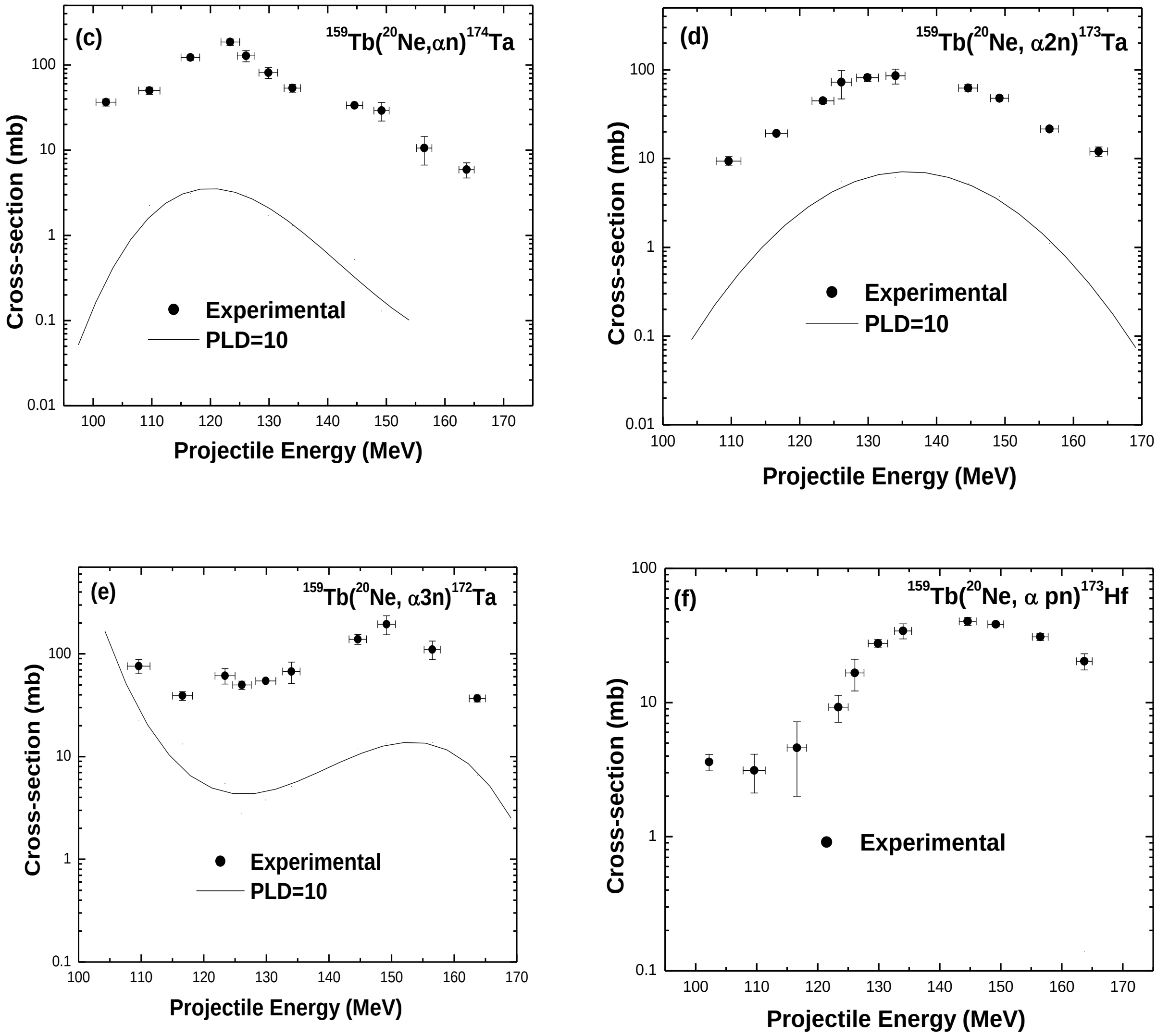


Fig.1: Excitation Function of the Evaporation Residues Produced in ^{20}Ne + ^{159}Tb Reaction. Solid Circles Represent Experimental Data. The Solid, Dotted and Dash Dotted Lines Correspond to the Theoretical Predictions of PACE-2 for Different Values of Level Density Parameter Constant PLD.

Conclusive Remarks

The Excitation Function (EF) of the six reaction products in the collision of ^{20}Ne with ^{159}Tb in the wide energy range 4.3-8.2 MeV/A have been measured. The experimentally measured cross-section have been compared by statistical model based computer code PACE-2. The enhancement in the measured cross-section in the α-emission channel, indicating the ICF process involving the break-up of ^{20}Ne- projectile into two fragments (^{16}O + α) in the field of the ^{159}Tb-target nucleus. One of them fuses with target nucleus and unfused fragments goes in the forward direction with out any interaction of the target nucleus. The PACE-2 code fails to explain the ICF-reaction.

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