Sum-Rule Model Studies for ^{14}N + ^{169}Tm

S. Kumar[1], I. Ahmed[1], Pankaj. K. Giri[2], Yashraj[1], and R. Kumar[1,*]
[1] *Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA and*
[2] *UGC-DAE Consortium for Scientific Research, Kolkata Centre, Kolkata 700098, India*

Introduction

In recent years, incomplete fusion reactions (ICF) were extensively studied in light and heavy-ion (L/HI) induced reactions at low energies around the Coulomb barrier, where complete fusion (CF) expected to be dominant reaction mode [1–3]. In case of CF projectile completely fuses with the target nucleus and forms an excited compound nucleus (CN), which de-excites via emission of lighter particles and γ-rays. However, in case of ICF, projectile breaks into two fragments in the vicinity of target nucleus, one of them fuses with target nucleus and forms an excited composite system, while remnant moves in forward direction with same velocity as of projectile. The composite system formed in ICF also de-excites via emission of light particles and γ-rays. ICF reactions were first observed in early sixties, where Britt and Quinton et al. [4] observed fast (non-evaporated) α-particles in the reaction of ^{12}C, ^{14}N and ^{16}O projectiles with Ni, Bi and Au targets. Later, similar phenomenon were reported by Galin et al. [5]. However, after that a large number of studies have been done to explore the dynamics of these reactions.

In more qualitative way, the CF and ICF reactions are disentangled on the basis of driving input angular momentum (l). Central collisions i.e. $0 \leq l \leq l_{crit}$ lead to CF due to availability of fusion pocket (for CF of projectile) in effective potential energy curve. The effective potential (sum of three potential viz. attractive nuclear potential, repulsive Coulomb and centrifugal potentials) is attractive in nature. However, for non-central collisions/at higher l - values ($l \geq l_{crit}$) repulsive centrifugal potential overcome the attractive nuclear potential, therefore, fusion pocket in the effective potential curve disappears or not enough to capture whole projectile. As a consequence, to sustain input l value projectile breaks into two parts and leads to ICF. The CN formed in case of CF have pre-determined mass/charge, excitation energy and angular momentum. However, in case of ICF composite system (CN formed due to partial fusion of projectile) have less mass/charge, excitation energy and higher l (due the non-central collision of projectile) as compared to CN formed via CF.

To understand ICF reaction dynamics several theoretical model have been proposed viz. Sum-Rule model [6], Break-up Fusion (BF)-model [7] and Promptly Emitted Particles (PEP)-model [8] etc. Wilczynski et al. [6], in their Sum-Rule model suggested that ICF comes naturally at higher value of l ($l \geq l_{crit}$) and occurs at non-central or peripheral collisions. According to the BF-model [7] it is assumed that projectile breaks into α-clusters (e.g., ^{14}N may break-up into ^{10}B + α) in target nuclear field which leads to partial fusion (ICF). But none of the aforementioned model explain ICF satisfactorily below 10 MeV/nucleon. In the present study, fusion l distribution window for the system ^{14}N + ^{169}Tm is interpreted with the Sum-Rule model at three different energies [9, 10]. Sum-Rule model is based on the idea of the generalized concept of critical angular momentum and partial statistical equilibrium.

Results and Discussion

According to the Sum-Rule model, the CF probability is nearly unity below l_{crit} and ICF starts contributing with CF only when $l \geq l_{crit}$. However, several recent studies [1–3] reported that ICF contributes significantly below the l_{crit}. For the better understanding,

*Electronic address: rakuiuac@gmail.com

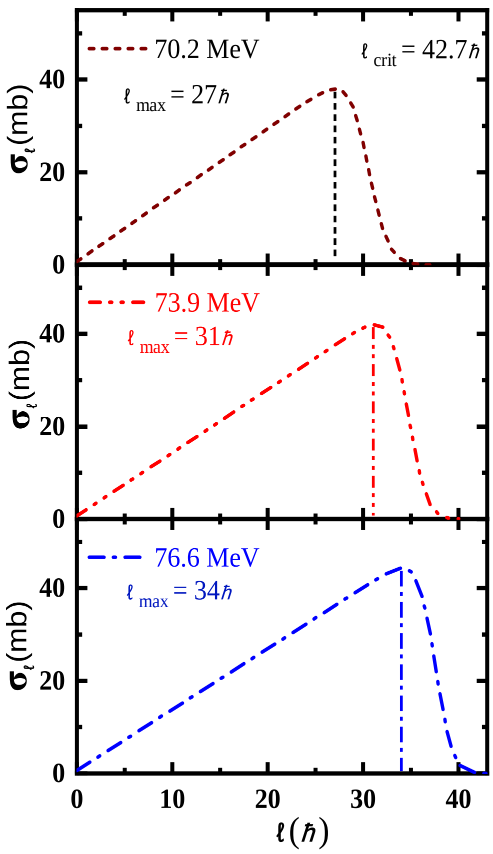

FIG. 1: Fusion l distribution for the system ^{14}N + ^{169}Tm at various projectile energies in centre of mass frame.

the fusion l-distribution for the system ^{14}N + ^{169}Tm is calculated at three studied energies [9, 10] using CCFULL [11] code and are presented in Fig 1. The l_{crit} for ^{14}N + ^{169}Tm system is calculated using the Wilczynski et al. [6] formalism and found to be 42.7 $\hbar$. The maximum value of angular momentum l_{max} at aforementioned energies is found to be 27, 31 and 34 $\hbar$ which is lower than the l_{crit} of the system. However, the previous measurements [9, 10] clearly reveals that ICF contribute significantly at these energies. Hence, the present work specifies that the existence of l waves below the l_{crit} which contributes for the ICF.

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References

[1] P. K. Giri et al., Phys. Rev. C **100**, 024621 (2019).

[2] P. K. Giri et al., Phys. Rev. C **100**, 054604 (2019).

[3] H. Kumar et al., Phys. Rev. C **99**, 034610 (2019).

[4] H. C. Britt et al., Phys. Rev. **124**, 877 (1961).

[5] J. Galin et al., Phys. Rev. C **9**, 1126 (1974).

[6] J. Wilczynski et al., Nucl. Phys. A **373**, 109 (1982).

[7] T. Udagawa and T. Tamura, Phys. Rev. Lett. **45**, 1311 (1980).

[8] J. Bondorf et al., Nucl. Phys. A **33**, 285 (1980).

[9] R. Kumar et al., Phys. Rev. C **96**, 054614 (2017).

[10] S. Kumar et al., J. Phys. G: Nucl. Part. Phys. **49**, 105103 (2022)

[11] K. Hagino et al., Comput. Phys. Commun. **123**, 143 (1999).