Role of Zeta Parameter in ^{16}O-Induced Reactions at Low Energies

Lupteindu Chhura[1], Dharmendra Singh[1, *], Nitin Sharma[1], Rajesh K. Sahoo[1], Rahul Mahato[1], Amritraj Mahato[1], Pankaj K. Giri[1, †], Sneha B. Linda[1], M. Afzal Ansari[2]

[1]*Department of Physics, Central University of Jharkhand, Ranchi, 835222, INDIA*

[2]*Department of Physics, Aligarh Muslim University, Aligarh 202002, INDIA*

. * *Email: dsinghcuj@gmail.com*

Introduction

There has been a significant interest in studying nuclear reaction mechanisms in heavy-ion (HI) induced reactions for several decades [1,2]. Among these mechanisms, the incomplete fusion (ICF) reaction stands out as one of the most dominant in heavy ion reactions along with complete fusion (CF). However, the significance of ICF cannot be overstated in the realm of heavy ion fusion reactions [2-5]. In nucleus-nucleus collision, ICF is very important in the description of complete reaction dynamics, as it constitutes a significant part of the total reaction cross-section. It is related to the beginning phase of nuclear interaction and plays a crucial role in elucidating the shift from one-body mean-field behavior at low energies to the onset of two-body nucleon-nucleon interactions at higher energies. Unlike in the CF process, where there is a total fusion between the projectile or its fragments and the target nucleus, there is a partial exchange of mass, linear, or angular momentum in the ICF process. Therefore, a clear and consistent study of ICF is essential to understand the nature of HI-induced reactions.

Over the past few years, there has been a surge of attempts to comprehend the low-energy ICF reactions and their dependence on different entrance channel parameters like mass asymmetry (μ_A), Coulomb Factor (Z_PZ_T), etc. There are several reports that reveal the significant impact of mass asymmetry and Coulomb factor on ICF [2-4]. A highly recent report also introduced the correlation between zeta parameter (ζ) and the low-energy ICF reaction dependency [3], as this parameter gives the combined effect of mass asymmetry and Coulomb factor. In this regard, an attempt has been made to see the combined effect of μ_A and Z_PZ_T, the ICF fractions (F_{ICF}) studied as a function of the ζ parameter. In the present work, the reactions of projectile ^{16}O with seven different targets have been taken into consideration for the analysis.

Theory

For a better understanding of the emergence and influence of the ICF processes, the contribution of the ICF reactions to the total fusion cross-section has been deduced as the percentage fraction of ICF at a particular energy and is defined as F_{ICF} (%) = [(σ_{ICF}/ σ_{TF}) × 100] %; where $\sigma_{TF} = \Sigma\sigma_{CF} + \Sigma\sigma_{ICF}$ at that particular energy.

The ζ parameter is defined as;

$$\zeta = Z_P Z_T \sqrt{\mu} = Z_P Z_T \sqrt{\frac{A_P A_T}{A_P + A_T}} = Z_P Z_T \sqrt{A_P \mu_A}$$

Where; $\mu = \frac{A_P A_T}{A_P + A_T} =$ Reduced Mass; and, $\mu_A = \frac{A_T}{A_P + A_T} =$ Mass asymmetry.

The data for the reaction systems ^{16}O + ^{148}Nd, ^{16}O + ^{124}Sn, ^{16}O + ^{115}ln, ^{16}O + ^{103}Rh, ^{16}O + ^{93}Nb, ^{16}O + ^{74}Ge, and ^{16}O + ^{45}Sc have been taken from Ref. [4-9]. In this analysis, an effort has been made to present the F_{ICF} as a function of ζ parameter at a particular value of relative velocity, that is V_{Rel} = 0.06c. The relative velocity of the nucleons in the compound nucleus has been widely used as a normalization factor to compare the F_{ICF} of different systems.

†*UGC-DAE Consortium for Scientific Research, Kolkata Centre, Kolkata 700106, INDIA*

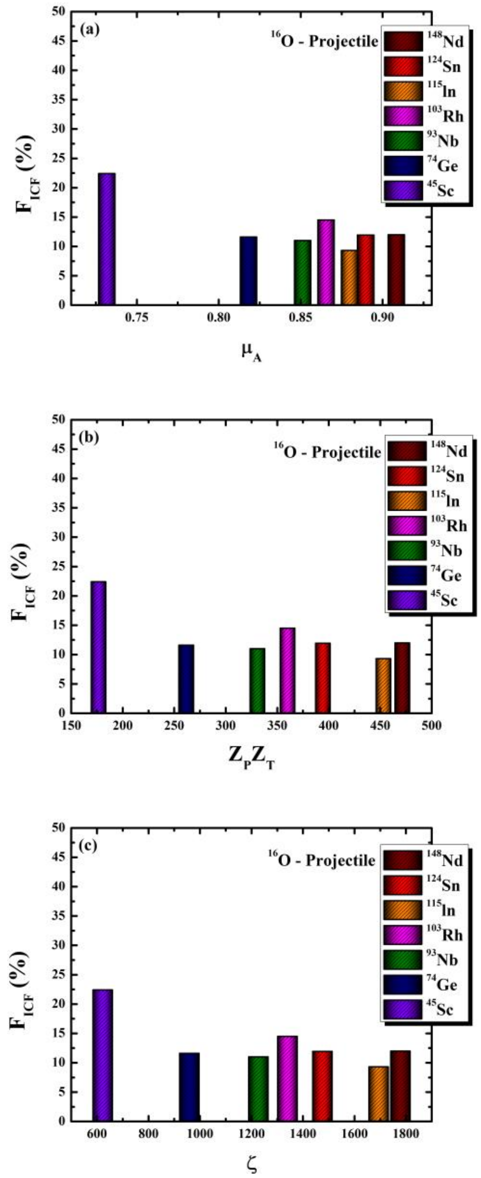

Fig. 1 Measured F_{ICF} (%) as a function of (a) μ_A, (b) Z_PZ_T, and (c) ζ parameter for the mentioned systems [4-9] at V_{Rel} = 0.06c.

Results and Discussion

The measured data of ICF for the above mentioned systems involving ^{16}O projectile were used to perform a systematic study. The F_{ICF}, which is a measure of the strength of ICF, was plotted as a function of well established entrance channel parameters mass asymmetry (μ_A) and Coulomb factor (Z_PZ_T) and shown in Fig.1 (a)-(b). As can be seen in these plots, the F_{ICF} shows a nearly similar pattern for these systems. This may be due to the fact that the μ_A and Z_PZ_T values for these systems are similar. The F_{ICF} value for the system ^{16}O + ^{45}Sc was found larger than expected. This may be due to the lower value of Coulomb barrier for this system at same value of V_{Rel}/c.

Further, the ICF fractions were also plotted as a function of zeta parameter (ζ), and displayed in Fig. 1 (c). It can be clearly seen in this plot that the ζ parameter shows clear agreement with ICF as indicated by the figures, considering the μ_A and Z_PZ_T. The ζ parameter, which includes Z_PZ_T as well as the mass dependence of the interacting nuclei, seems a reasonably good parameter to understand the ICF reaction dynamics at low energies.

Further work is in progress to explain ζ parameter and its relation with Sommerfeld parameter (η), which is important for explaining nuclear reactions in a more convincing way.

Acknowledgments

The authors would like to extend their gratitude to the Head of the Physics Department at CUJ, Ranchi, for providing continuous motivation and support throughout this study.

References

[1] H. C. Britt *et al.*, Phys. Rev. 124, 877 (1994).
[2] A. Mahato *et al.*, Eur. Phys. J. A 56, 131 (2020).
[3] S Kumar *et al.*, J Phys G: Nucl Part Phys, 49, 105103 (2022).
[4] P. K. Giri *et al.*, Phys. Rev. C 100, 024621 (2019).
[5] D. Singh *et al.* Phys. Rev. C 97, 064610 (2018).
[6] K. Kumar *et al.*, Phys. Rev. C 88, 064613 (2013).
[7] Unnati *et al.*, Nucl. Phys. A 811, 77 (2008).
[8] A. Sharma *et al.*, J. Phys. G 25, 2289 (1999).
[9] D. Singh *et al.*, J. Phys. Soc. Jpn. 82, 114201 (2013).