Investigation of Breakup Fusion of ^{16}O Projectile with ^{154}Sm Target through Universal Fusion Function Approach

Rahul Mahato[1], Dharmendra Singh[1*], Amritraj Mahato[1†], Rajesh K. Sahoo[1], Lupteindu Chhura[1], Nitin Sharma[1], Pankaj K. Giri[1††], Sneha B. Linda[1], Harish Kumar[2], Suhail A. Tali[2], Rahbar Ali[3], S. Kumar[4], Nabendu K. Deb[5], M. Afzal Ansari[2], R. Kumar[4], S. Muralithar[4], and R.P. Singh[4]

[1]Department of Physics, Central University of Jharkhand, Ranchi, 835222, INDIA
[2]Deptartment of Physics, Aligarh Muslim University, Aligarh- 202002, INDIA
[3]Department of Physics, G. F. (P. G.) College, Shahjahanpur - 242001, INDIA
[4]Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA
[5]Department of Physics, Gauhati University, Guwahati, Assam - 781014, INDIA
** Email: dsinghcuj@gmail.com*

Introduction

Fusion reactions involving heavy nuclei, such as ^{16}O (a strongly bound nucleus with an equal number of protons and neutrons), are essential for advancing our understanding of nuclear interactions across various energy levels. The dynamics of these reactions, particularly when the projectile interacts with heavier targets, are significantly influenced by the structural characteristics of the projectile itself. In recent years, the study of incomplete fusion (ICF) and complete fusion (CF) has emerged as a pivotal area of investigation in nuclear physics [1,2,3]. CF occurs when the entire projectile fuses with the target nucleus, resulting in the formation of a highly excited compound nucleus that subsequently decays by emitting light particles. In contrast, ICF involves only partial fusion of the projectile, with a portion remaining as a spectator that transfers momentum to the target nucleus.

Various theoretical models have been proposed to explain ICF dynamics, including the Sum-rule model and the Breakup Fusion model. Yet, these models have often failed to accurately reproduce experimental data, especially at energies below 10 MeV/nucleon. This ongoing challenge underscores the need for continued research to refine our understanding of ICF processes and their dependence on entrance channel parameters.

In this context, our study focuses on the breakup effects of the strongly bound projectile ^{16}O on fusion cross sections when interacting with ^{154}Sm at energies above the Coulomb barrier. By employing a reduction method [4] that effectively removes geometric and static potential effects, the influence of the breakup process on the CF function is isolated, allowing for a direct comparison against the universal fusion function (UFF). This approach enables us to explore how the breakup of ^{16}O affects the overall fusion dynamics, providing valuable insights into the intricate interplay between projectile structure and fusion outcomes.

Experimental Technique

The experiment was conducted using the 15UD Pelletron accelerator facility at the Inter University Accelerator Centre (IUAC), New Delhi, India. A beam of ^{16}O ions was utilized to bombard isotopically enriched targets of ^{154}Sm. The target foils were prepared via the vacuum evaporation deposition technique to ensure uniform thickness and composition. The target thickness was optimized to be around 200–500 μg/cm². Thick aluminum backing foils were used to support the targets. For the irradiation, the target-aluminum foil assemblies were positioned in the General Purpose Scattering Chamber (GPSC). The ^{16}O beam was directed at an energy of 100 MeV. To maintain optimal conditions during the experiment, the stack was irradiated, during which the beam current was monitored using a Faraday cup located behind

† Present Affiliation- Department of Physics, Dr. Shyama Prasad Mukherjee University, Ranchi, 834008, India
†† Present Affiliation- UGC-DAE Consortium for Scientific Research, Kolkata Centre, Kolkata 700098, India

the stack. Following the irradiation, the activities of the produced evaporation residues (ERs) were measured using an offline gamma spectroscopy method. The gamma rays emitted from the decay of the ERs were recorded with a High Purity Germanium (HPGe) detector. The data acquisition was managed using the CANDLE software, which is PC-based and designed for spectroscopic analysis. The energy and efficiency of the HPGe detector were calibrated using a standard ^{152}Eu gamma-ray source of known strength. The identification of the ERs produced in the ^{16}O+^{154}Sm system was accomplished through the detection of their characteristic gamma rays in the recorded spectrum, confirmed by analyzing their decay curves and half-lives.

Analysis and results

To gain deeper insights into CF and ICF dynamics, the experimental cross-sections have been analyzed using the UFF framework. By removing geometric and static potential effects of interacting nuclei, the UFF allows us to compare measured fusion functions (MFFs) with a universal baseline as shown in Fig. 1.

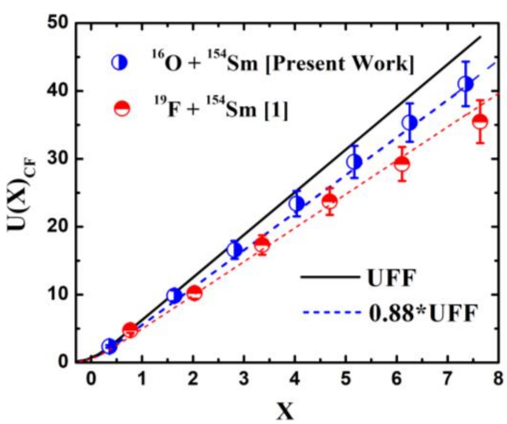

Fig. 1 The measured fusion functions (MFFs) along with universal fusion function (UFF) for the systems ^{16}O+^{154}Sm and ^{19}F+^{154}Sm [1]. The UFF is represented by the solid line, and dotted line represents suppression factor 0.88 multiplied by UFF.

The reduction procedure [4] expresses the fusion cross sections and incident energy in terms of dimensionless variables, leading to a simplified analysis of the fusion process. The fusion cross section σ_{Fus} and the incident energy E_{CM} (in the center-of-mass frame) are reduced to the dimensionless fusion function U(x) and variable x, defined as:

$$U(x) = [\frac{2E_{CM}}{\hbar\omega R_B^2}]\sigma_{Fus} \quad \text{and} \quad X = \frac{E_{CM} - E_{CB}}{\hbar\omega}$$

Here, $\hbar\omega$ represents the curvature of the Coulomb barrier, R_B is the barrier radius, and E_{CB} is the Coulomb barrier.

The present results indicate an approximately 12% suppression of measured CF cross-sections compared to UFF predictions. This suppression arises from the breakup of the ^{16}O projectile into ^{12}C and α particles, leading to ICF. The discrepancy between UFF and MFF underscores the significant role of projectile breakup in the fusion dynamics of this system.

Further, an attempt has been made to compare the fusion suppression observed in the present system with previously reported ^{19}F+^{154}Sm [1] system. From figure 1 it has been observed that the fusion suppression for ^{19}F induced system is 0.79*UFF, while for the present system it is 0.88*UFF. Here, it is important to mentioned that the α-Q value of ^{19}F projectile is lower than the ^{16}O projectile. Therefore, higher magnitude of fusion suppression is observed in ^{19}F induced system. This signifies the projectile structure plays an important role in defining the ICF dynamics at above barrier energies.

Further analysis is in progress.

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