Theoretical analysis of fusion excitation function measurement for $^{18}O + ^{116}Sn$ system

Nabendu Kumar Deb[1],* Harun Al Rashid[1,2], Amar Das[1,3], Kushal Kalita[1]
[1]*Nuclear Detector R&D Lab, Department of Physics, Gauhati University, Jalukbari, Guwahati – 781014, India*
[2]*Department of Physics, BBK College, Nagaon, Barpeta - 781311, India*
[3]*Department of Physics, Suren Das College, Hajo – 781102, India*
** email: nd_globe@yahoo.co.in*

Introduction

Nuclear fusion cross section around the Coulomb barrier reveals varieties of phenomena. One such phenomenon is the enhancement of the sub-barrier fusion cross section as compared to the theoretical predictions of 1-D barrier penetration model (BPM) [1]. Such enhancement occurs due to the coupling of relative motion to internal degrees of freedom of the colliding nuclei such as deformation [2], vibration [3], nucleon transfer [4] and neck formation [5] between the two interacting nuclei. These couplings often lessen the barrier height by modifying the one dimensional Coulomb barrier into multiple potential barriers which then cause enhancement of fusion cross-sections [6]. With the theoretical models available, these effects of inelastic excitations could be explained reasonably well within the quantum coupled channel (QCC) approach and the empirical coupled channel (ECC) approach [7]. However, the role of the neutron transfer on the heavy ion sub-barrier fusion is still not fully resolved. This is mainly because of the challenges to account for the intricate mechanism of transfer channels in the theoretical models, as the chargeless neutron, unaffected by the Coulomb barrier, can freely flow from one collision partner to the other even at large internuclear distances [8].

Neutron transfer plays a vital role in the enhancement, especially, for the systems having positive Q value of few neutrons transfer, as it causes a considerable shift in the barrier height [9]. A series of studies were done, eventually, to extricate the PQNT effect on the fusion cross section. It has been observed that a large enhancement of fusion cross-section below the uncoupled Coulomb barrier occurred due to neutron transfer channels for some of the fusing systems having positive Q-value for the transfer channel. On the contrary, there are some systems having PQNT channels which do not show any enhancement of the sub barrier fusion cross sections [1]. Recently, fusion excitation function measurement was carried out for the $^{18}O + ^{116}Sn$ system and has been observed that positive Q-value for the neutron transfer channels for this system plays the role behind the enhancement of the sub-barrier fusion cross section [10]. This was evident as in Fig. 1 when it was compared with the similar system [11] having negative Q-value in the reduced scale [9]. Here, in this work, theoretical analysis has been done further using semi-classical approach via ECC model of Zagrabaev et al. [7] to further ascertain the role of neutron transfer.

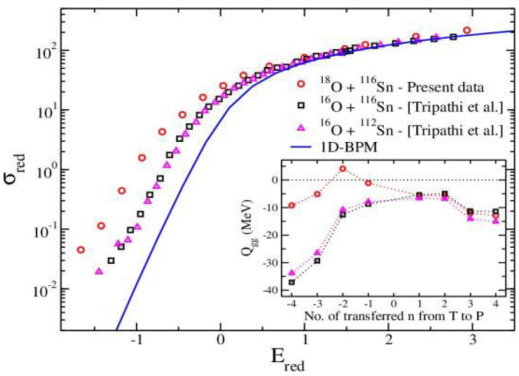

Fig. 1 Comparison of fusion excitation function for similar systems in reduced scales along with their Q-values for various neutron transfer in its inset.

This model includes inelastic as well as multineutron transfer channels for fusion cross-section calculations. In the ECC approach , the neutron rearrangement was consistently incorporated using the semi-classical approximation for the transfer probability [4].

This method is not fully microscopic, but it approximately accounts for the neutron transfer channel with positive Q-values. This model was successfully used with neutron transfer channel in various systems [4]. This model can include up to four neutron transfer channels in the calculations. But due to the swift decrease in the probability of the transfer of neutrons with increasing number of neutrons to be transferred, only 1n and 2n transfer channels with positive Q-values plays a significant role [12].

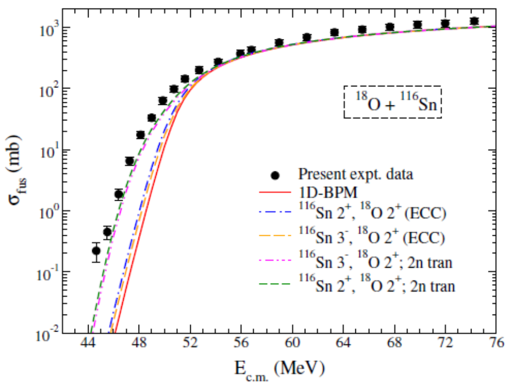

Fig. 2 The experimentally measured excitation function is compared with the different modes of coupling between interacting partners using ECC model. They are shown by different curves.

Theoretical Analysis

As shown in Fig. 2, the fusion excitation functions due to inelastic channels were obtained without considering the coupling due to transfer channels. Following this, neutron stripping channels were successively added. It can be observed that the 2n stripping channel enhanced the sub-barrier fusion cross-section to an extent that it reproduced the entire experimental data appropriately. The inelastic single phonon vibration of 2^+ state of the target and 2^+ state of the projectile alongwith the neutron transfer channel reproduced the data better. The inelastic mode availed here during the calculation alongwith transfer channel were only single phonon mode of vibrations of both the nuclei. Double phonon vibration mode could not be included in the ECC code, but nevertheless, the result nearly matched. Therefore, even through this code, the role played by the neutron transfer appears to be significant in the present system.

Summary

The experimentally measured fusion excitation function for $^{18}O+^{116}Sn$ having positive Q-value for 2n transfer channel was compared with the coupled-channels calculations using ECC model. Experimental fusion cross-sections were found to be significantly larger with respect to results from 1D-BPM calculation. Reasonable fits to the data were obtained by considering various inelastic couplings in the coupled-channels calculation. But inclusion of the 2n stripping channel along with inelastic excitation resulted in the best reproduction of the fusion excitation function, thereby establishing that positive Q-value for neutron transfer effect may play a decisive role in enhancing fusion cross-section in the sub-barrier region for the present system.

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