Influence of 2p transfer channels on sub-barrier fusion

Parvdeep Goyat, Simran Rani, and Pardeep Singh*
Department of Physics,Deenbandhu Chottu Ram University of Science & Technology,Murthal Haryana India

Introduction

The continuous advancement in accelerators and detection techniques and importance in stellar nucleosynthesis and superheavy elements make the fusion reaction one of the widely investigated reaction channel during last few decades. Consequently, a lot of work has been done to study the effects of various factors that affect the sub barrier fusion like the structure of colliding nuclei, effect of coupling of excited states and nucleon transfer channels [1, 2]. Recent studies have shown that neutron transfer channels having positive Q-values produced significant enhancement in sub barrier fusion [3]. However, the effect of coupling of positive Q-value proton transfer(PQPT) channels has not been studied much and needs to be explored more. In this conference contribution, we aim to examine the effect of coupling of 2p (proton) stripping channel in addition to consideration of excited states of projectile and target on the fusion reactions ^{32}S + ^{100}Mo and ^{32}S +^{89}Y using the coupled channels approach.

Coupled Channel Calculations

To investigate the effect of incorporation of the intrinsic degrees of motion such as collective excitations and structural deformities of the interacting nuclei along with couplings to 2p transfer channels the coupled channels calculations through code CCFULL [4] has been performed for fusion reactions ^{32}S + ^{100}Mo and ^{32}S +^{89}Y having positive Q-value for 2p stripping channel. In the calculations nuclear potential parameters, energy and deformation parameters of inelastic states of the colliding nuclei are required and Akyuj-Winther parameterization scheme has been utilized to calculate the potential parameters for wood-saxon potential [5]. The values obtained for geometrical parameters of potential such as depth (V_0), range (r_0)and the diffuseness(a_0) are given in table I while the values for the energies and deformation parameters has been taken from ref [6, 7] and are listed in table II. In order to account the change in Coulomb energy which is associated with charged particle transfer, instead of Q-value Q_{eff} has been used. Here $Q_{eff} = Q + \delta V_C$, with δV_C accounts the difference in the Coulomb energy at the fusion barrier radius arises due to transfer of charged particle.

TABLE I: Akyuj-Winther (AW) potential parameters (V_0, r_0, a_0).

Systems	V_0(MeV)	a_0(fm)	r_0(fm)
$^{32}S + ^{89}Y$	69.177	0.665	1.176
$^{32}S + ^{100}Mo$	70.552	0.667	1.177

TABLE II: Excitation energies(E_λ) along with corresponding deformation parameters(β_λ) of excited states(λ^π) of colliding partners used in coupled channel calculations.

Nucleus	λ^π	E_λ(MeV)	β_λ
^{32}S	2^+	3.290	0.168
^{89}Y	2^+	2.011	0.104
	3^-	2.742	0.208
^{100}Mo	2^+	0.535	0.230
	3^-	1.908	0.155

Results and Discussion

Figure 1 and figure 2 shows the calculated fusion excitation functions for ^{32}S + ^{89}Y and ^{32}S + ^{100}Mo reactions respectively. It has been noticed from figures that the results of 1D-BPM calculations are quite far from the data for both the systems in the sub-barrier region. So excited states of projectile and target were included to remove this discrepancy. It is observed from figure 1 that for system ^{32}S + ^{89}Y, coupling of target vibrational states 2^+ produced negligible effect in fusion cross section however the inclusion of target vibrational state 3^- brought noticeable enhancement in the fusion cross sections as compared to no coupling but still the calculations could not match the experimental results. Further, the incorporation of vibrational state (2^+)enhanced the cross sections significantly and reproduced the data quite well. Since this system has positive Q-value for proton stripping channel(Q_{eff}-value=4.672 MeV), coupling to 2p transfer channel was also included but negligible effect of coupling to transfer channel has been observed. Now, for system ^{32}S + ^{100}Mo as observed in figure 2 coupling of 2^+,3^- vibrational states of target incremented the fusion cross section significantly but fails to explain

*Electronic address: panghal005@gmail.com,pardeep.phy@dcrustm.org

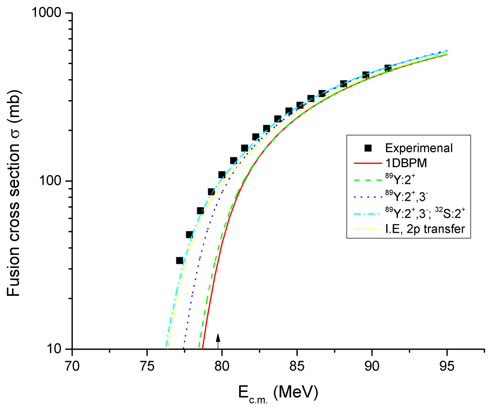

FIG. 1: Calculated fusion excitation function for ^{32}S + ^{89}Y system with coupling of excited states of colliding nuclei and proton transfer channel(denoted by lines). Experimental data (denoted by symbols) has been taken from ref [8].

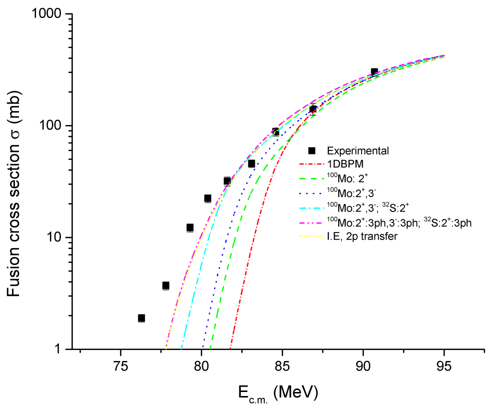

FIG. 2: Calculated fusion excitation function for ^{32}S + ^{100}Mo system with coupling of excited states of colliding nuclei and proton transfer channel(denoted by lines). Experimental data (denoted by symbols) has been taken from ref[9].

the experimental results in the below barrier region. Further, inclusion of coupling of vibrational state (2^+) of projectile enhanced the fusion cross section but couldn't remove the gap between the data and predictions in the sub-barrier region. So multi-phonon excitations of vibrational state of projectile and target(three-phonon coupling of 2^+,3^- state) were incorporated in the calculations which consequently explain the data quite well except at very low energies. Furthermore 2p stripping channel ($Qeff$-value=9.382 MeV) was also included but negligible effect of coupling of transfer channel has been observed for this system.

Conclusion

CC calculations have been performed for reactions induced by ^{32}S on ^{89}Y and ^{100}Mo targets to exhibit the contribution of coupling of proton transfer channel in addition to coupling of low-lying excited states of reactants. Coupling of excited states of reactants produced enhancement in sub-barrier region for ^{32}S + ^{89}Y system which consequently moves the calculations towards data whereas for system ^{32}S + ^{100}Mo additional consideration of multi-phonon coupling of reactant vibrational states has been required to reproduce the data. Importantly, it has been noticed that coupling to 2p proton stripping channel has no effect on fusion cross sections for these systems.

References

[1] R.N Sahoo,M. Kaushik et al., Phys. Rev. C 99 (2019) 024607.

[2] H.M Jia, C.J Lin et al., Phys. Rev.C 89 (2014) 064605.

[3] S. Rani and P. Singh, Nucl. Phys. A 1036 (2023) 122669.

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

[5] R. A. Broglia and A. Winther, I (1981 Benjamin/Cummings Publ. Company), 1981.

[6] S. Raman, C. W. Nestor , At. Data Nucl. Data Tables, 78 (2001) 43.

[7] T. Kibedi and R. H. Spear, At. Data Nucl. Data Tables 80 (2002) 35.

[8] A.Mukherjee,M.Dasgupta et al.,Phys.Rev. C 66 (2002) 34607.

[9] R.Pengo,D.Evers et al., Nucl. Phys. A 411 (1983) 255.