Influence of phonon coupling and transfer channels in $^{36}S +^{58} Ni$ fusion reaction at energies around Coulomb barrier

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Introduction

Heavy-ion fusion reaction cross sections are affected by couplings of the relative motion of fusing nuclei to the nuclear intrinsic degrees of freedom such as shape deformations,vibrations and nucleon transfer channels[1].Sub-barrier fusion cross sections are enhanced(in magnitude) with respect to predictions of 1-Dimensional Barrier Penetration model (BPM) when these couplings are taken into account[2].Significant contribution of these couplings can also be observed via splitting of the single peaked Coulomb barrier into group of discrete barriers[3].The barrier energies and probabilities are a characteristic of the couplings specific to the internal structure of the projectile and target[4, 5].Thus barrier distribution(BD) function is one of the important observable to investigate the detailed effects of channel coupling at energies around Coulomb barrier. Further the extensive study has been done regarding the role of coupling to neutron transfer channels but the effect of inclusion of proton transfer channels is still an open area for research.In the present contribution we have theoretically analysed the fusion excitation function of the system $^{36}S +^{58} Ni$,which has positive Q-value for 2p proton pickup channel.Corresponding Barrier Distribution(BD) function has been extracted in order to investigate the detailed effect of coupling of inelastic excitations and proton transfer channel.

TABLE I: Excited states(λ^{π}) along with excitation energies(E_{λ})and the corresponding deformation parameters(β_{λ})used in coupled channel calculations[7].

Systems	λ^{π}	E_{λ}(MeV)	β_{λ}
^{36}S	2^{+}	3.290	0.168
^{58}Ni	2^{+}	1.45	0.18
	3^{-}	4.47	0.22

Coupled Channel Calculations

Coupled channel(CC) calculations with various target-projectile coupling schemes have been performed using the code CCFULL[6]. We have used Wood-Saxon form for the nuclear part of total interaction potential with depth V_0=65.39MeV, radius r_0=1.153fm and the diffuseness a_0=0.63fm for $^{36}S +^{58} Ni$ system.In addition to this the values of energy and deformation parameter of excited states of target and projectile used in the calculations are shown in table.In order to account for change in Coulomb energy which is associated with charged particle transfer, instead of Q-value we have used Q_{eff} where $Q_{eff} = Q + \Delta V_C$, ΔV_C accounts the difference in the Coulomb energy at the fusion barrier radius due to transfer of charged particle.The barrier distributions are derived from the second derivative of $(E_{c.m.}\sigma_f)$with respect to $E_{c.m.}$,using the three-point difference formula, with an energy step of $E_{c.m.} = 1.48$ MeV below the Coulomb barrier(CB) and 2.48 MeV above the CB.

Results and Discussion

The calculated fusion reaction cross section and barrier distribution(BD) for the system

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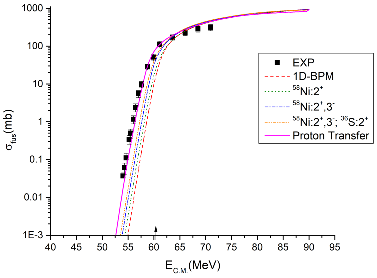

FIG. 1: Calculated fusion excitation function for the system $^{36}S +^{58} Ni$. Fusion cross sections including target and projectile inelastic excitations (I.E.) are shown by different curves (as shown in legend).Data (solid squares) are taken from[8]. Arrow represents the Coulomb barrier.

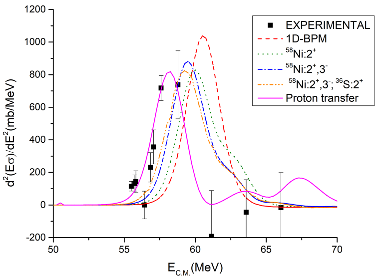

FIG. 2: Experimental (solid squares) barrier distribution for $^{36}S +^{58} Ni$. CC calculations, including the target and projectile inelastic couplings and proton pair-transfer coupling, are shown with lines

$^{36}S +^{58} Ni$ are shown in Fig 1 and 2 respectively. As observed from figure 1 that 1D-BPM model calculations are very far from experimental results.Nevertheless notable enhancement in fusion cross section has been noticed on inclusion of coupling of excited states of target and projectile in the sub-barrier region.As seen from BD, on inclusion of vibrational state 2^+ of target, barrier peak shifted towards lower energy and a small shoulder appears at around $E_{C.M.}$= 62.75 MeV.Further inclusion of state 3^- of target just shifted the main peak towards lower energy side.The fusion excitation function and BD is merely influenced by addition of excited state of projectile as it merely shifted the main peak by around 0.25 MeV. Due to positive Q_{eff}-value(1.529 MeV) for two proton pickup channel for $^{36}S +^{58} Ni$ system here we have also included the coupling to proton transfer which eventually transferred the barrier peak towards lower energy thus leading to enhancement of fusion cross section and reproduced the entire shape of BD as well as the fusion excitation function.

Conclusion

In conclusion here we have investigated the effect of coupling of excited states of target and projectile in conjunction with proton transfer channels and established that an enhancement has been observed due to coupling of inelastic excitations of projectile and target and proton transfer channels in below barrier region.It has been observed that coupling of collective excitation 2^+ in ^{58}Ni leads to appearance of small peak-like structure on higher energy side of BD.Furthermore it has been noticed that for the system $^{36}S +^{58} Ni$,coupling to proton transfer channels found out to be essential as it leads to reproduction of entire shape of BD as well as the fusion excitation function.

References

[1] S. Kalkal, et al., Phys. Rev. C **81**, 044610, (2010).

[2] S. Mandal,et al., Phys. Rev. C, bf 96, 014614, (2017).

[3] M. Dasgupta et al.,Annu. Rev. Nucl. Part. Sci. 48, 401 (1998).

[4] G. Kaur et al., Phys. Rev. C **97**, 064606 (2018).

[5] D. BourginZ. et al., Phys. Rev. C. **90**, 044610 (2014).

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

[7] S. Raman,C. W. Nestor Jr., and P. Tikkanen, At. Data Nucl.Data Tables 78, 1 (2001)

[8] A. M. Stefanini, et al.,Physics Letters B ,162 (1985) 66