Probing the influence of positive Q-value transfer channels on the fusion cross-sections

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Introduction

Heavy-ion nuclear reaction studies offer a wide range for exploring and understanding the reaction dynamics. The internal degrees of freedom substantially affect the reaction cross-sections. The couplings to internal degrees of freedom result in the distribution of barriers instead of a single barrier leading to enhancement of fusion cross-sections near and below barrier energies in comparison to the predictions of one-dimensional barrier penetration model (1d-BPM). The fusion excitation functions were analysed for ^{30}Si + ^{58,62,64}Ni and ^{32,34,36}S + ^{58,64}Ni [2] systems within the coupled channel (CC) formalism using CCFULL code in order to disentangle the role of coupling to different inelastic and transfer channels with Q > 0 on the sub-barrier fusion. The aim was to understand the channel coupling effect of positive Q-value neutron transfer (PQNT) channels (2n pick-up/stripping) and effect of the magnitude of positive Q-value on sub-barrier fusion cross-sections.

Coupled channel calculations

The coupled channel calculations were performed using the quantum mechanical code CCFULL [3]. The energy independent Woods-Saxon parameterisation for the nuclear potential is used in the entrance channel. A pair-transfer coupling between the ground states is included in CCFULL code by utilizing the macroscopic coupling form factors [4]. The excitation energies (E_{ex}) of different states and the corresponding deformation parameters β_λ were used from ref. [2].

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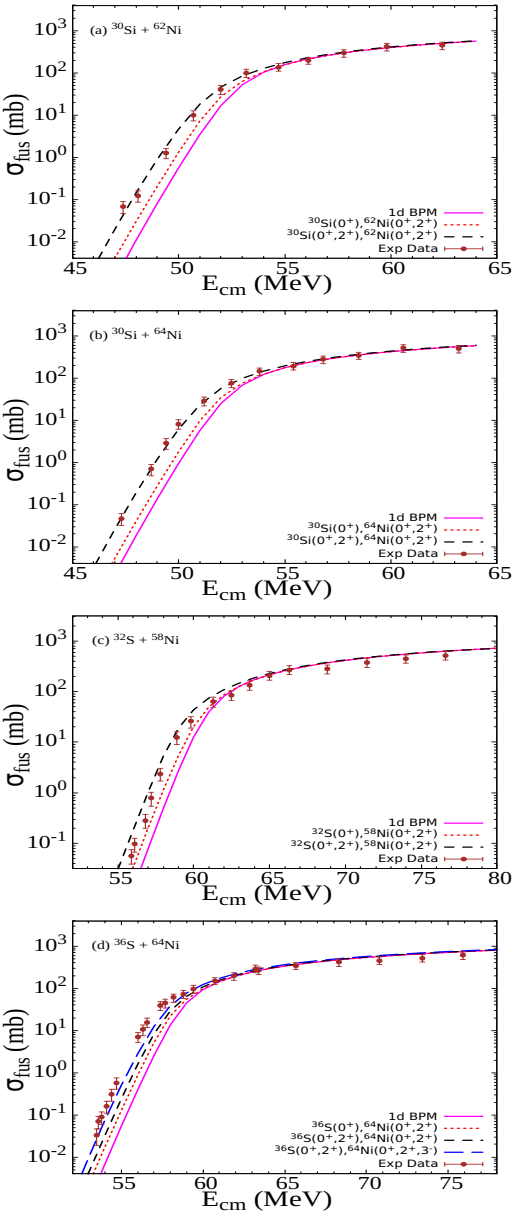

FIG. 1: 1d-BPM, CC calculations and experimental fusion cross-sections for: (a) ^{30}Si + ^{62}Ni, (b)^{30}Si + ^{64}Ni, (c) ^{32}S + ^{58}Ni and (d) ^{36}S + ^{64}Ni. The solid line (1d-BPM), dot(red), dash (black), and long dash (blue) lines represent different couplings of projectile/target included. Experimental data is taken from ref. [2].

Results and Discussion

For ^{30}Si + ^{62,64}Ni, ^{32}S + ^{58}Ni and ^{36}S + ^{64}Ni systems no positive Q-value transfer channel exists. It has been found that the coupling to collective excitations of the projectile and target in these systems play a significant role in sub-barrier enhancements of fusion cross-sections. In case of ^{30}Si + ^{62,64}Ni and ^{32}S + ^{58}Ni systems, the inclusion of 2^+ states of both projectile and target explained the data to a good approximation (Fig. 1a,b and c). For ^{36}S + ^{64}Ni system, the coupling to inelastic states of ^{36}S (2^+) and ^{64}Ni ($2^+, 3^-$) resulted in the sub-barrier fusion enhancement and explained the results (Fig. 1d).

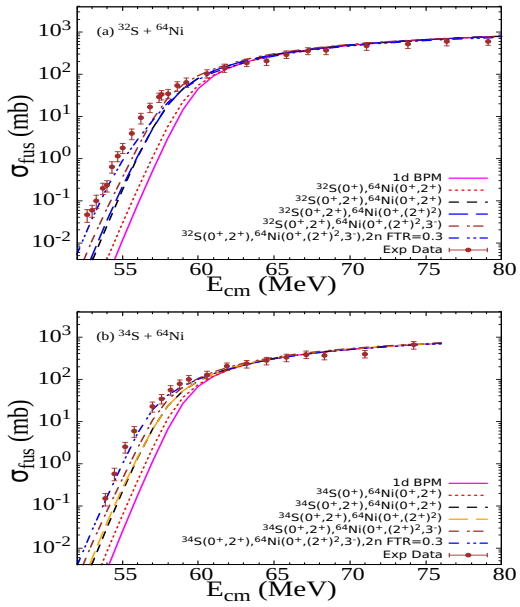

FIG. 2: 1d-BPM, CC calculations and experimental [2] fusion cross-sections of: (a) ^{32}S + ^{64}Ni and (b) ^{34}S + ^{64}Ni systems. The solid line (1d-BPM), dot (red), dash (black), long dash (blue), dash-dot(brown), dash-dot-dot (blue), long dash (yellow) and dash dot-dot (blue) represents different couplings of projectile/target involved.

Positive Q-value two-neutron pick-up channel exists for ^{32}S + ^{64}Ni (Q = +3.563 MeV). In addition to coupling to the inelastic excited states of ^{32}S, coupling to the two phonons of 2^+ and single phonon of 3^- vibrational state of ^{64}Ni showed a significant enhancement in fusion cross-section. Further, coupling to the 2n pick-up transfer channel with a transfer strength FTR = 0.3 showed an additional enhancement of the sub-barrier fusion cross-sections and explained the data well (Fig. 2a). For ^{34}S + ^{64}Ni system, the Q-value for 2n pick-up channel is +0.379 MeV. The coupling to the single phonon of 3^- vibrational state and 2n pick-up channel with FTR = 0.3 explained the experimental results (Fig. 2b). The role of various inelastic and transfer channels for these reaction systems have been summarized in Table 1. It was observed that in case of ^{32,34}S + ^{64}Ni systems that the two neutron pick-up transfer channels has a significant contribution in explaining the results irrespective of magnitude of the positive Q-value.

TABLE I: Summary of the channel coupling effects for various reactions.

Reaction system	CC considered (inelastic/transfer)	Sub-barrier fusion enhancement observed
^{30}Si + ^{58}Ni	inelastic	Yes
	2n stripping	No
^{30}Si + ^{62}Ni	inelastic	Yes
^{30}Si + ^{64}Ni	inelastic	Yes
^{32}S + ^{58}Ni	inelastic	Yes
^{32}S + ^{64}Ni	inelastic	Yes
	2n pick-up	Yes
^{34}S + ^{58}Ni	inelastic	Yes
	2n stripping	No
^{34}S + ^{64}Ni	inelastic	Yes
	2n pick-up	Yes
^{36}S + ^{58}Ni	inelastic	Yes
	2n stripping	No
^{36}S + ^{64}Ni	inelastic	Yes

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