Studies on the fusion reaction dynamics induced by heavy ions around the coulomb barrier

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Fusion cross sections, in heavy ion-induced reactions, at sub-barrier energies are found to be enhanced significantly over the predictions of the one-dimensional barrier penetration model [1,2]. Such observations have been elucidated in terms of static deformations, couplings of inelastic excitations and the positive Q value neutron transfer (PQNT) channels. The coupling with intrinsic degrees of freedom has an effect of changing the height of the barrier. Barriers lower than the one-dimensional Coulomb barrier; will lead to the enhancement of fusion cross sections.

The role of inelastic couplings for the sub-barrier fusion cross section has been well established using theoretical formalism within the coupled-channel (CC) approach. However, the precise effect of transfer channels has been seemingly elusive in many cases. For neutron (neutral particle) transfer, reaction may occur at a very large distance resulting in fusion enhancement. Therefore the PQNT effect on fusion at sub-barrier energies becomes an important topic of present interest. For some systems, the sub-barrier fusion enhancement has been correlated to the presence of PQNT channels however, for many systems having PQNT channels; its role could not be ascertained. Such ambiguous observations suggest that PQNT channels may not be sufficient but is of high importance to illustrate the sub-barrier fusion enhancement. Keeping all this in mind, fusion excitation measurements have been performed for ^{16}O+^{61}Ni, ^{18}O+^{61,62}Ni, ^{18}O+^{116}Sn systems and, therefore, were reported in this thesis. ^{16}O+^{61}Ni possess negative Q values for all the neutron transfer channels. Other systems, considered in this work, possess positive Q value for 2n stripping channel. O, Ni and Sn are all spherical nuclei with the lowest quadrupole and octupole states being collective in nature. ^{18}O has 2n outside the ^{16}O core. The energy of the first 2^+ state of ^{18}O and ^{16}O is 2 MeV and 7 MeV respectively. Also, both ^{61,62}Ni possess similar collective strengths, thereby making the experimental signature of transfer couplings noticeable while comparing these O+Ni systems.

Experiments have been performed at the Inter-University Accelerator Centre (IUAC), New Delhi, India using a recoil mass separator, Heavy-Ion Reaction Analyser (HIRA) [3,4]. ^{16,18}O beams obtained from 15UD Pelletron accelerator were bombarded on ^{61,62}Ni, ^{116}Sn targets prepared using physical vapour deposition in the target lab of IUAC [5,6]. The targets were ≈ 100 μg/cm^2, ≈ 150 μg/cm^2 and ≈ 150 μg/cm^2 thick respectively prepared on ≈ 30 μg/cm^2 C-backing. The fusion cross-sections have been determined at different energies by measuring the evaporation residues (ER). The ERs were identified via gating between time of flight (TOF) and corresponding energy loss suffered by the ERs in the cathode of MWPC (ΔE). The ΔE-TOF spectra so obtained for all the systems display the clear separation between ERs and other unwanted beam like particles [3,4].

The fusion cross-sections have been measured for these systems in laboratory energies ranging from ~ 11 - 16% below to ~ 31 - 46% above the barrier energy. In this energy range, the contribution due to fission is found to be negligible. On comparing the measured fusion cross section with the CC calculation using the code CCFULL [3,4], the enhancement could be observed in the sub-barrier region for all these systems compared to that of the simple theoretical predictions. Fig. 1 shows the fusion excitation function for ^{16}O+^{61}Ni, ^{18}O+^{61,62}Ni, ^{18}O+^{116}Sn systems.

The result of ^{18}O+^{116}Sn system was analyzed using CC calculations including various low-lying inelastic excitations and transfer channels [3]. Both ^{18}O and ^{116}Sn were considered as vibrators. Various modes of inelastic excitations including 2^+ or 3^- vibrational states of ^{116}Sn or mutual coupling of both these excited states or mutual coupling of $(2^+)^2 \times (3^-)^2$ states of ^{116}Sn were considered one after another in the calculations. Eventually projectile excitations were also coupled. No such combinations could explain the data in all energy regimes. When the 2-phonon excitations of the 2^+ vibrational state of ^{18}O is invoked by coupling it mutually with the 1-phonon coupling of 2^+ and 3^- states of ^{116}Sn, the result seems to reproduce the experimental data fairly well in the whole energy range. This system has Q value of +4.081 MeV for the 2n stripping channel. So the neutron transfer channels were included in the coupling scheme next to see the PQNT effect through transfer coupling strength parameter of 0.3 MeV for 2n transfer along with the inelastic excitations. The result then gives the best fit to the data. However, coupling transfer channel with inelastic excitations of 1-phonon and 2-phonon vibrational states of the target and the projectile respectively under predicts the inelastic excitations of the same collective states very slightly. The effect of neutron transfer, here, appears to be a small reduction of the fusion cross section at most energy. The magnitude of this reduction is shown as the inset of Fig. 1 (bottom right). Hence, the role played by PQNT due to the 2n transfer channel in this system appears to be quite significant.

The result of ^{16}O+^{61}Ni, ^{18}O+^{61,62}Ni systems were also analyzed using CC calculations including various low-lying inelastic excitations and transfer channels [4]. All the ^{16,18}O, ^{61,62}Ni isotopes were considered as vibrators. For ^{16}O+^{61}Ni system, it is observed that considering the coupling scheme of the 1-phonon 2^+ state of ^{61}Ni with that of the 2^+ state of ^{16}O, the experimental data could be reproduced quite well. As this system does not possess +Q values for the neutron transfer channels, neutron transfer couplings were not considered. For ^{18}O+^{61}Ni system, it is seen that considering inelastic excitations of various modes, the experimental data could not be reproduced. But on considering 2n transfer coupling with transfer form factor being 0.45 MeV, the experimental data could be reproduced quite well, thereby showing the positive effect of PQNT behind the enhancement of the cross section for this system. Even for ^{18}O+^{62}Ni, simple inelastic coupling due to both the colliding nuclei is found to be insufficient for the reproduction of the experimental data. But on considering 2n transfer coupling with transfer form factor being 0.3 MeV, the data could be reproduced quite well, thereby showing the role played by PQNT channel for this system. Thus overall, it could be inferred that PQNT plays the role in those systems considered here having +Q values for 2n transfer channel. More detailed results and discussions will be presented during the conference.

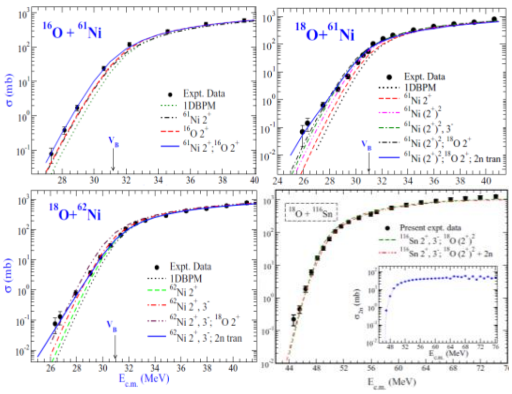

Fig. 1 The experimentally measured excitation function with different modes of coupling between interacting partners using CCFULL for ^{16}O+^{61}Ni (top left), ^{18}O+^{61}Ni (top right), ^{18}O+^{62}Ni (bottom left) and ^{18}O+^{116}Sn (bottom right).

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