Investigation of multinucleon transfer reactions and their coupling effects on the fusion reaction mechanism around the Coulomb barrier for ^{28}Si + ^{90,94}Zr systems

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In the present thesis, an investigation of the multinucleon transfer reactions and their effects on the fusion reaction mechanism around the Coulomb barrier for ^{28}Si+^{90,94}Zr systems has been presented. In the light mass systems, the coupling effects are not noticeable and for very heavy systems, there are several open channels making the coupled channels calculations very complicated. Hence, for the study of the channels coupling effects, medium mass nuclei are the ideal ones.

Three experiments have been performed for this thesis work using 15UD pelletron accelerator at Inter University Accelerator Centre, New Delhi. In the first experiment, the fusion excitation functions have been measured for ^{28}Si+^{90,94}Zr systems around the Coulomb barrier in order to investigate the role of multinucleon transfer reactions in the sub-barrier fusion enhancement [1], using Heavy Ion Reaction Analyzer (HIRA) [2]. The transmission efficiency of HIRA and the angular distributions of the evaporation residues were also measured at lab energy of 103 MeV. The targets used for the experiments [3] were fabricated in target lab of the IUAC, New Delhi. Both the isotopes have similar and small B(E2) and B(E3) [4] values which give rise to similar inelastic coupling strengths. All the transfer channels have negative Q-values in the case of ^{28}Si+^{90}Zr system, whereas, upto four neutron pick-up channels have positive Q-values in ^{28}Si+^{94}Zr system. Therefore, the role of multinucleon transfer can be disentangled from the inelastic couplings in the sub-barrier fusion enhancement. It was found that for both the systems, the experimental fusion cross sections were strongly enhanced compared to the predictions of the one dimensional barrier penetration model (1-d BPM) below the barrier. Coupled channels formalism (CCFULL code [5]) was employed to explain the sub-barrier fusion cross section enhancement, theoretically. The Akyuz-Winther parameterization of potential was used while performing CCFULL calculations without any attempt to vary the parameters to fit the above barrier data. The coupled channels calculations using these parameters reproduced the data reasonably well. The enhancement could be explained by considering the coupling of low-lying inelastic states of the projectile and target in the ^{28}Si+^{90}Zr system. In the sub-barrier region, the measured fusion cross sections for ^{28}Si+^{94}Zr turned out to be about an order of magnitude higher than the ones for ^{28}Si+^{90}Zr system, which could not be explained by coupling to inelastic states alone, giving clear evidence of the importance of multinucleon transfer channels with positive Q-values in the sub-barrier fusion cross section enhancement as ^{90,94}Zr both are believed to have similar collective strengths.

In the second experiment, the study of multinucleon transfer reactions between ground states and excited states for the ^{28}Si+^{90,94}Zr systems around the Coulomb barrier was carried out using HIRA. Most of the measurements performed in this experiment were in the sub-barrier region so that the transfer form factors could be extracted in the same energy region where maximum enhancement in the fusion cross section is observed. At the target chamber, the 14 elements BGO array was mounted for gamma detection in coincidence with the recoils reaching the focal plane of HIRA to obtain ground state and excited state transfer strengths. The excitation energy distribution for the above mentioned systems were extracted and the theoretical calculations were performed using the semi-classical code GRAZING [6]. The transfer form factors, transfer probabilities and the slope parameters were extracted at the barrier height. The excited state transfer in ^{28}Si+^{94}Zr was found to be much higher than that for ^{28}Si+^{90}Zr system, which may be either due to the negative Q-values or due to the neutron shell closure in the case of ^{90}Zr. From the results obtained, it was found that the simultaneous transfer is also an important mechanism of multinucleon transfer reactions at the sub-barrier energies, which may be due to the pairing correlations being stronger in the ground state transfer. Another evidence of pairing correlations observed in these systems is the odd-even staggering observed for multinucleon transfer probabilities at the barrier radius. As the Z-identification was not possible, from Q-value considerations it turned out that pick-up channels were neutron transfer whereas stripping channels were proton transfer. From the excitation spectra, it was also observed that the excitation energy spectra become broader as the beam energy was increased which might be due to excited state transfer taking place at higher energies. In case of ^{28}Si+^{94}Zr, slope parameter was almost the same for two, three and four nucleon pick-up channels. In case of ^{28}Si+^{90}Zr, the slope parameter for two neutron pick-up was less than that for one neutron pick-up. It was found that the transfer probabilities were much higher in the case of ^{28}Si+^{94}Zr as compared to the ^{28}Si+^{90}Zr which further confirms the fact that there is some strong correlation between the transfer reactions and the fusion mechanism.

The third experiment was performed in the General Purpose Scattering Chamber to measure transfer reaction cross sections for the same systems at an energy much above the barrier (120 MeV). Though the mass identification was not possible in these measurements, but a very clean Z-separation was obtained. The angular distributions for one and two proton stripping were extracted for both the systems, and the theoretical calculations were performed using quantum mechanical coupled channels code, FRESCO [7]. A reasonably good agreement was obtained between experimental results and the theoretical predictions.

The work reported in this thesis emphasizes the role of multinucleon transfer channels in sub-barrier fusion cross section enhancement as there are very few systems where the role of multinucleon transfer has been investigated, although a large number of systems has been studied for exploring the role of one and/or two nucleon transfer channels. Very few measurements for the multinucleon transfer channels have been performed in the same energy region in which the fusion cross section enhancement is significant. The multinucleon transfer reactions in the sub-barrier region is like the flow of electrons two superconductors separated by an insulator, and may help in experimentally establishing the analog of Josephson effect in material sciences.

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