Study of some Heavy-Ion Reactions with stable and weakly bound projectiles using Coupled-Channel formalisms

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Introduction

Experimental and theoretical studies have revealed that fusion reactions are strongly affected by couplings of the relative motion of the colliding nuclei to nuclear intrinsic motion which causes enhancements of the fusion cross section at sub-barrier energies over the prediction of a one dimensional barrier penetration model [1, 2].

Coupled-channel (CC) approach help us to understand particular excitation modes of one or both of the collision nuclei on the reaction outcome. The coupled-channel equations are set up for relative motion of the nuclei including all relevant channels. The coupled-channel equations are solved by imposing the IWBC condition to simulate the strong absorption inside the Coulomb barrier such that the incoming flux does not return back. In this CC formalism, the real nuclear potential usually is assumed to have a Woods-Saxon (WS) form whose depth is chosen to reproduce the experimental fusion cross section at high energies. In the present thesis, CCFULL [3] program has been used which solves the coupled-channel equations to compute fusion cross section of compound nucleus taking into account the coupling to all orders.

In the present thesis, we have investigated the effect of nuclear deformation parameter (β_N) of spherical target nuclei on the fusion cross section and fusion barrier distribution of some heavy-ion reactions.

The role of breakup on fusion has been strongly deliberated both theoretically and experimentally in the literature. CCFULL calculations show an enhancement in fusion at energies below the barrier and suppression in fusion at energies above the barrier compared to the predictions given by the one dimensional barrier penetration model. The systematic study of suppression of complete fusion (CF) in reactions involving weakly bound nuclei such as ^{6}Li and ^{7}Li as a projectile with different light, medium and heavy spherical and deformed targets at energies near and above the Coulomb barrier has been studied in the present thesis.

Standard coupled-channel code CCFULL uses WS potential which is a deep attractive nuclear potential. Instead of such an approach with the WS potential, the CCFULL code is modified using the Proximity potential of Blocki [4] as the nuclear potential which however, is shallow potential as compared to the WS potential. In particular, the effect of this Proximity potential with the CC calculations for different spherical and deformed projectile – target combinations have been investigated in the present thesis.

Calculation details and discussion

In the present study, the detailed CC analysis for heavy-ion reactions ^{16}O+^{120}Sn, ^{16}O+^{208}Pb and ^{28}Si+^{120}Sn are carried out using CCFULL code. In this calculations, the appropriate low-lying vibrational excitations of the target nuclei *i.e.* 2^+ and 3^- vibrational state of ^{120}Sn, 3^- and 5^- vibrational state of ^{208}Pb and 2^+ and 4^+ rotational states of ^{28}Si are considered [5]. The agreement between the calculations and the experimental data is improved only when the β_N is chosen to be greater than the coulomb deformation parameter (β_C) of the spherical target nucleus. Therefore it is evident that the coupling to the quadrupole phonon state in the spherical nucleus with $\beta_2^N > \beta_2^C$ is needed to explain the experimental fusion data of ^{16}O+^{120}Sn and ^{28}Si+^{120}Sn and the coupling to the octupole phonon state with $\beta_3^N > \beta_3^C$ is needed to explain the experimental fusion data of ^{16}O+^{208}Pb. The effect of transfer channel on fusion cross section and fusion barrier distribution with CC calculations for above reactions are also investigated in this thesis.

To investigate the influence of the breakup of the projectile on the CF at energies above the

Coulomb barrier, the CC calculations for reactions induced by ^{6}Li and ^{7}Li on various targets are re-analyzed using CCFULL code. These calculations are performed with the WS potential as a nuclear potential that reproduce the derived value of the uncoupled bare potential which is taken from the corresponding references. Using these potential parameters and appropriate couplings of reacting nuclei, the CF cross sections are calculated for different reactions. In the present work, the couplings of relevant low-lying rotational states and vibrational states of all reacting nuclei have been included which giving the large suppression at energies above the barrier. However, it is interesting to note that the calculated cross section agrees well with the measured CF cross sections when multiplied by some factor over the entire energy range. This multiplying factor called the fusion suppression factor is obtained in such a way that the calculated cross section fit well with the experimental data at the highest energy. It is found that the CF suppression factor is larger for the heavy target nucleus compared to that for the medium target and smallest suppression is found for the lighter nuclei. Hence the comparison between ^{6}Li and ^{7}Li induced CF suppression for different targets shows that the CF suppression do exhibit a dependence on atomic number/charge of the target nucleus.

In the present thesis, the CC calculations with modified Proximity potential of fusion cross section and fusion barrier distribution of some spherical and deformed projectile and target combinations such as ^{16}O+^{144}sm, ^{208}Pb, ^{120}Sn and ^{154}Sm, ^{28}Si+^{120}Sn and ^{24}Mg+^{208}Pb is carried out using the modified CCFULL code. In these calculations, the appropriate low-lying excitations of target and projectile nucleus are taken. In this study, the values of the surface energy constant γ_0 and the surface asymmetry constant k_s and the width of the nuclear surface b of the potential have been chosen in such a way that the calculated fusion cross section fit well with the experimental fusion cross section data at higher energies. These calculations are also compared with the available experimental data and the standard WS calculations. These calculations with the modified Proximity potential well reproduce the experimental fusion cross section as well as fusion barrier distribution.

Conclusion

The present study of increment in the β_N of the target nuclei are consistent with other theoretical work with different reactions. From the present study, we have concluded that the nuclear deformation parameter plays a significantly important role in fusion reaction near the Coulomb barrier and it may have different value from β_C which indicates the importance of nuclear couplings over the coulomb couplings.

From the systematic study of suppression of CF in reactions involving weakly bound nuclei such as ^{6}Li and ^{7}Li as a projectile with different light, medium and heavy spherical and deformed targets, it can be concluded that for a particular projectile, the suppression increases with the increase in the atomic number/charge of the target nucleus and for a particular target, the suppression increases with a decrease in the breakup energy of the projectile nuclei. Therefore it indicates that this suppression in CF cross section is mainly due to the breakup of the projectile in the Coulomb field of the target nucleus.

The calculations using the modified Proximity potential is found to be adequate in CC calculations for the analysis of the heavy-ion fusion reactions when the potential parameters are chosen appropriately.

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