Chapter 6

Summary and Conclusions

In the present thesis, studies on elastic scattering angular distributions, fusion cross sections and barrier distributions from quasi-elastic scattering excitation functions have been carried out with ^{6,7}Li projectile nuclei at around the Coulomb barrier energies. The main focus of the present work is to investigate the role of projectile breakup on various reaction channels such as elastic scattering and fusion. For the ^{7}Li + ^{27}Al system, simultaneous measurement of elastic scattering and fusion cross sections has been carried out. Influence of breakup and transfer couplings on elastic scattering have also been investigated by CDCC and CRC formalism. Secondly, for ^{7}Li + ^{159}Tb system, elastic scattering angular distributions have been investigated to study the energy dependences of optical potential parameters. The CDCC calculations have also been performed for ^{7}Li + ^{159}Tb system. In another investigation for ^{6,7}Li + ^{209}Bi systems, fusion barrier distributions have been studied from the measurement of quasi-elastic scattering at backward angles. In this reactions, breakup and/or transfer coupling effects are also investigated using CDCC-CRC formalism. Thus, the present work, involves the measurements and study of elastic scattering angular distributions, fusion cross sections and fusion barrier distributions to address the role of projectile breakup which are described briefly for all the above systems, as given below:

- **Simultaneous study of elastic scattering and fusion cross sections for ^{7}Li + ^{27}Al system:**

  Simultaneous measurement of elastic scattering angular distributions and fusion cross sections has been carried out for ^{7}Li + ^{27}Al system in the energy range from below to above the Coulomb barrier energy. This experiment has been carried out at 6MV Folded Tandem Ion Accelerator (FOTIA) Facility (Sec:3.1.2)at BARC, Mumbai, India. In this work, elastic scattering angular distributions have been measured at various energies from 8.0 MeV to 16.0 MeV. In the same experimental setup the α-evaporation energy spectra were measured at backward angles, to obtain the fusion cross sections. The energy calibration of ΔE+E telescope detectors were done by discrete groups of α-particles with known energies produced in the ^{12}C(^{7}Li,α)^{15}N reaction.

  Energy dependence of the optical potential parameters have been obtained by analyzing elastic scattering angular distributions with Woods-Saxon form of the potential. The consistencies of real and imaginary parts of the potential were checked by dispersion relation analysis. Thus, from the behavior of the optical model potentials, no strong conclusion regarding the presence of the 'TA' or the 'BTA' could be made which is consistent with earlier results in the literature. The total reaction cross sections have also been obtained. In order to investigate the breakup and transfer(1n-stripping) coupling effects on elastic scattering angular distributions, the coupled channels calculations by CDCC and CRC formalisms, have been carried out using FRESCO code. In comparison to the breakup coupling, the effect of transfer(1n-stripping) is found dominant due to the positive Q-value of 1n-stripping reaction. The calculated (^{7}Li-inelastic) and 1n-stripping cross sections nearly explained the experimental data that are available in the literature [68] at three energies (E_{lab} = 11 MeV, 14 MeV and 18 MeV).

  The total fusion cross sections have been derived by reproducing the experimentally measured α-evaporation energy spectra using Monte Carlo statistical model code PACE [49]. The deduced fusion cross sections from the present measurement were compared with the literature fusion data that have been obtained for the same reaction ^{7}Li + ^{27}Al at above the Coulomb barrier(V_b=6.6 MeV) energy. The obtained fusion cross sections are in good agreement with the literature data at above the barrier energy and are also well explained by the CCFULL calculations. The present fusion cross sections and the total reaction cross sections derived from the optical model analysis of the elastic scattering data are in close agreement with the results from CDCC+transfer calculations.

- **Investigation of threshold anomaly for ^{7}Li + ^{159}Tb system:**

With an aim to study the energy dependence of optical potential parameters, complete angular distributions for the scattering of ^{7}Li projectile on ^{159}Tb target have been carried out for the energies at around the Coulomb barrier($V^{b}_{c.m.}$=26.6 MeV). This experiment was done at BARC-TIFR pelletron accelerator facility in Mumbai, India. The measured elastic scattering angular distributions were analyzed using ECIS code. In this analysis, the Woods-Saxon form of potential was used to describe the elastic scattering angular distributions. The extracted real and imaginary parts of the optical potential have been investigated as a function of energy. The observed behavior of these optical potentials were confirmed by the dispersion relation calculation. The obtained behavior of real and imaginary parts of the potential may suggest the presence of the 'Threshold Anomaly' for ^{7}Li + ^{159}Tb system.

Elastic scattering angular distributions have also been interpreted by continuum discretized coupled channels calculations (CDCC). Due to the low breakup threshold energy of ^{7}Li projectile, it was necessary to check the breakup coupling effect and nature of real and imaginary parts of the dynamic polarization potentials(DPP) that might affect the characteristics of potential parameters and presence of 'Threshold Anomaly'. The observed total effect of the real and imaginary parts of the dynamic polarization potential (DPP) is attractive in nature that reduces the barrier and may responsible for the enhancement in the fusion cross sections. Also, the behavior of dynamic polarization potentials(DPP) with respect to the radius R favors the indication of 'Threshold Anomaly'. The possible reason may be due to the net polarization potential, composed by competing attractive and repulsive parts that depends strongly on the bound state of ^{7}Li-projectile and target inelastic contributions.

The extracted total reaction cross sections from the present measurements have been compared with the other systems that involve ^{7}Li projectile and different target masses such as ^{16}O, ^{27}Al, ^{28}Si, ^{59}Co, ^{64}Zn, ^{112}Sn, ^{208}Pb and ^{232}Th. This comparison includes the reduced reaction cross sections to suppress the differences arising from the size and the charges of different systems [75]. It was observed that at below barrier energy, target masses may play role by reducing the total reaction cross sections as the magnitude of target mass increases.

- **Fusion barrier distributions in ^{6,7}Li + ^{209}Bi reactions:**

  Quasi-elastic scattering excitation functions have been measured at backward angles at 140° and 160° for the ^{6,7}Li + ^{209}Bi systems. This experiment was performed using 14UD BARC-TIFR pelletron facility. The fusion barrier distributions have been obtained by taking the single derivative of dσ_{qe}/ dR. In this analysis, quasi-elastic channel includes elastic, inelastic and breakup and/or transfer (breakup-α). The results of the experimental barrier distributions with and without including breakup and/or transfer (breakup-α) channel are compared with the available fusion barrier distributions that have been obtained from the fusion excitation functions[85]. Without including the breakup and/or transfer (breakup-α) channel to the elastic plus inelastic, the resulted experimental barrier distributions were observed to be shifted towards lower energy side in comparison to the peak positions of the available fusion barrier distributions for both the ^{6,7}Li + ^{209}Bi systems. Thus, the barrier distributions obtained from quasi-elastic that includes breakup and/or transfer (breakup-α) channel can explain the fusion barrier distributions obtained from the fusion excitation function. The transmission (capture probabilities) ($T_{\circ}$) from the quasi-elastic excitation functions are obtained from the relation $T = 1 - R$ which have been compared with the one obtained from the fusion excitation functions. This shows reasonable agreement at near barrier energies for both the reactions of ^{6,7}Li with ^{209}Bi.

The quasi-elastic excitation functions and corresponding barrier distributions were also interpreted by the detailed coupled channels calculations that involves simple coupled channels, continuum discretized coupled channels and coupled reaction channels calculations. In the simple coupled channels calculations, the resonant states of ^{6,7}Li were considered as inelastic channels. This calculations could describe the quasi-elastic (elastic+inelastic) excitation functions and corresponding barrier distributions reasonably well. However, when breakup channel be a part of quasi-elastic channel, CDCC calculations are useful to explain the resulting fusion barrier distributions. Therefore, continuum discretized coupled channels calculations have been done to describe the quasi-elastic excitation functions and corresponding barrier distributions. In case of weakly bound projectile (such as ^{6,7}Li) that posses cluster structure may directly breakup into two fragments (core + fragment) or the breakup may occur after some nucleon transfer (pickup/ stripping). So, to understand the effect of transfer channel on quasi-elastic excitation function and corresponding barrier distribution, CRC calculations were done for 1n-stripping channel in case of ^{6}Li + ^{209}Bi system. The present calculation shows negligible effect of 1n-stripping on quasi-elastic excitation function. In the literature, it has been observed that for stable weakly bound projectile (^{6}Li) the 1n-stripping is found more preferable channel that leads to (p + α) and the contribution from 1n,1p-pick up is found negligible at below barrier energy in the reaction with ^{207,208}Pb and ^{209}Bi targets[87]. Motivated by these experimental results, simultaneous calculation for breakup and 1n-transfer have been attempted to reproduce the relative contribution of breakup and 1n-stripping channels using CDCC-CRC formalism for the reaction of ^{6}Li with ^{208}Pb and ^{209}Bi. The binding energies for core and valence particles are taken as 0.1MeV and the spectroscopic amplitudes are set at 2.0. The results show very good agreement with the experimental observation for relative contribution of breakup and $1n$-stripping reaction.

Future outlook

In recent years heavy ion reaction studies with stable and weakly bound nuclei(^{6,7}Li, ^{9}Be) at near barrier energies have been of great interest due to the advent of unstable weakly bound nuclei. The similarity in structural properties of stable and unstable weakly bound nuclei has enhanced the importance of reaction studies with stable weakly bound nuclei which can serve a testing ground for unstable weakly bound nuclei. Due to the low breakup thresholds of these nuclei breakup coupling affects all the associated reaction channels like elastic scattering, inelastic, fusion, transfer etc. This suggest that for the better understanding of breakup coupling effects experimentally, all these channels should be measured simultaneously. The similar measurements can also be implemented to the reactions which involve radioactive ion beams (RIBs). In the literature separate measurements are available with different target mass nuclei. Development of theoretical model which can describe all the relevant reaction channels simultaneously, is also a big challenge for theoretical physicists.