CHAPTER - 6

Summary and Conclusions

In the recent years the study of the heavy ion nuclear reactions, especially the couplings with the various channels has achieved a great interest, which is mainly occurring in the vicinity of the Coulomb barrier. It is important to study the elastic scattering on different projectile target combinations with varying asymmetry, in order to understand more complicated reactions. The cross-section of elastic scattering can help to obtain an optical potential which is necessary to understand the entrance and exit channel potentials of some transfer reactions. Breakup effects also play an important role in the scattering mechanism, affecting the interaction potential. One of the important points of investigation is whether the effect of breakup is essential to increase the total reaction cross-section. Therefore, it is important to investigate the dependence of the breakup and total reaction cross-sections near the barrier energies.

In the present thesis, reaction mechanism study involving weakly bound nuclei (^{6}Li & ^{7}Li) and radioactive ion beam (^{8}Li) projectile on the light and medium – mass target (^{9}Be, ^{51}V, ^{116}Sn, ^{112}Sn) was investigated. The angular distributions of elastic scattering ^{6}Li + ^{116}Sn at E_{lab} = 20, 21, 22, 23, 26, 30 and 35 MeV, ^{6}Li + ^{112}Sn at E_{lab} = 21, 23, 25 and 35 MeV, ^{7}Li + ^{116}Sn at E_{lab} = 18, 19, 20, 21, 22, 23, 24, 26, 30 and 35 MeV, ^{8}Li + ^{9}Be at E_{lab} = 19.6 MeV, ^{8}Li + ^{51}V at E_{lab} = 18.5 MeV were measured. Thus in the present work the elastic scattering measurements were carried out at the energies close to Coulomb barrier so as observe the energy dependence of the optical potential (OP). The total reaction cross sections have also been extracted by the optical model fitting of the experimental data and these were compared with other systems involving tightly bound, stable weakly bound, and radioactive and halo projectiles with targets in the same mass range. Also the effect of breakup channel on the elastic angular distributions for ^{6}Li + ^{116}Sn system has been studied. As the knowledge about the reaction mechanism of the weakly bound nuclei is limited, whereas the recent successful developments of radioactive ion beams, only motivated this research work, where both the above mentioned nuclei was used as projectiles.

To study the elastic scattering and breakup of the weakly bound nuclei ^{6,7}Li, experiment was done at the Bhabha Atomic Research Centre – Tata Institute of Fundamental Research (BARC – TIFR) Pelletron facility, Mumbai, India. The beams were delivered by the 14UD

Pelletron accelerator. The experimental details of which can be found in Chapter 3 and Chapter 4. The elastic scattering cross–section using the radioactive ion beam ^{8}Li were measured at the 8UD Pelletron accelerator of the University of São Paulo, Brazil for which details are mentioned in Chapter 5. The present studied reactions are the following:

(1) The near barrier elastic scattering reaction of ^{6}Li + ^{116,112}Sn along with the measurement of total reaction cross section of the present and other systems were carried out, to investigate the presence / absence of Breakup Threshold Anomaly (BTA). Also the effect of breakup couplings on ^{6}Li + ^{116}Sn system has been measured.
(2) Investigation of the threshold anomaly and total reaction cross section in the near barrier elastic scattering reaction of ^{7}Li + ^{116}Sn and the comparison of the total reaction cross section of the other systems with the present system were done.
(3) Elastic scattering and total reaction cross section using the radioactive ion beam ^{8}Li on ^{9}Be and ^{51}V targets were measured and total reaction cross section of the present systems were compared with others.

In the first experiment where the weakly bound projectile ^{6}Li was used, the effort was made to measure the elastic scattering angular distributions at different bombarding energies starting from much below to much above the Coulomb barrier. The beam was delivered from the 14UD Pelletron accelerator at TIFR, Mumbai, India and bombarded on a 450 μg/cm^2 self supported enriched ^{116}Sn (≥ 98%) target and also on 540 μg/cm^2 self supported enriched ^{112}Sn (≥ 99.5%) target, and the elastically scattered ^{6}Li ions were detected by three solid-state silicon surface barrier detectors in $\Delta E + E$ telescopic arrangements. Two monitors were used for the absolute normalization purpose. The angular distributions were measured in steps of 2.5°–5° at angles from 20° to 173° at lower energies and from 20° to 105° for higher energies. The optical model analyses of the energy dependence of the interaction potential, performed by two different kinds of potentials viz., phenomenological Woods-Saxon potential (WSP) and double folded São Paulo potential (SPP) , show the absence of the usual Threshold Anomaly (TA), corresponding to the presence of the so-called Breakup Threshold Anomaly (BTA). This behavior is attributed to the repulsive polarization potential produced by the breakup process. The total reaction cross

sections for the above systems were also derived and compared with other systems like halo, weakly bound and tightly bound projectiles on targets with similar masses.

The analysis of total reaction cross sections for several systems with similar target masses indicates that the breakup increases the total reaction cross section in such a way that the neutron-halo ^{6}He projectile-induced reactions have larger cross sections than the not so weakly bound lithium isotopes, which, however, have larger cross sections than the tightly bound projectiles investigated. Also we have measured near-barrier α – production cross sections for the weakly bound nucleus ^{6}Li on ^{116}Sn. CDCC calculations have been performed considering the exclusive Coulomb and nuclear breakup along with the exclusive breakup cross section measured at various energies which clearly indicates alphas coming from the breakup channel along with the other reaction mechanisms, like the evaporation of complete and incomplete fusion, transfer and so on.

In the second experiment, once again the attempt was made to measure the elastic scattering angular distributions at different bombarding energies starting from much below to much above the Coulomb barrier for the system ^{7}Li + ^{116}Sn. The ^{7}Li nucleus has breakup (α + t) threshold energy of 2.47 MeV and one bound excited state at 0.48 MeV, and thus the stripping of one neutron may have large positive Q values for several target nuclei, the attractive component of the dynamic polarization potential in the scattering of this projectile may be comparable or even predominates over the repulsive dynamic polarization potential due to the breakup. The experiment was performed at TIFR, Mumbai, India, and the beam was bombarded on a 430 μg/cm^2 self supported enriched ^{116}Sn (≥ 98%) target and the elastically scattered ^{7}Li ions were detected by a four solid state silicon surface barrier ΔE + E telescopic arrangement. Here only one monitor was used for the absolute normalization. The angular distributions were measured in steps of 2.5° to 5° at angles from 20° to 173° at lower energies and from 20° to 105° for higher energies. Similar results were observed by performing the optical model analyses as in the case of ^{6}Li, that is, the absence of the threshold anomaly (TA). It has been observed that for several systems with ^{6}Li as projectile show a clear behaviour typical of the threshold breakup anomaly (BTA), including the one with the same ^{116}Sn target. We explain these behaviours by the fact that the scattering of weakly bound nuclei are affected by the repulsive polarization potential

produced by the breakup process, important even at energies below the Coulomb barrier, but for the specific case of ^{7}Li there is a strong competition between this repulsive polarization potential and the attractive polarization potential produced by the bound ^{7}Li excited state and transfer reactions. For ^{7}Li, these two components of the polarization potential have similar strengths and the net result is an almost energy independent optical potential. This result cannot be extrapolated for every target, because the relative importance of the polarization potential produced by the different reaction mechanisms may vary with the target structure. The derived total reaction cross sections for the above system were compared with other systems, that is, halo, weakly bound, and tightly bound projectiles on targets with similar masses for which the same conclusion has been obtained, that is, the halo projectile has the largest cross section than the weakly and tightly bound nuclei. The comparison of the total reaction cross section has also been made with the ^{6}Li + ^{116}Sn system, for which it has been found that, the total reaction cross section for the ^{6}Li + ^{116}Sn system is larger than for ^{7}Li + ^{116}Sn system, corresponding to larger breakup cross section for the former than for the later. The dispersion relation analysis for phenomenological Woods - Saxon model has also demonstrated for the two systems, that is, ^{6}Li + ^{116}Sn and ^{7}Li + ^{116}Sn, to check the energy dependence of the optical potential near the barrier, showing the presence of BTA in both the systems.

In the third experiment too, the elastic scattering angular distributions were measured on the two different targets but with the single energy set only. The projectile here used was the radioactive ion beam (RIB) ^{8}Li. The experiment using the radioactive ion beam was carried out at the 8UD Pelletron accelerator of the University of São Paulo, Brazil. The secondary radioactive ion beam ^{8}Li was produced with the RIBRAS (Radioactive Ion Beams in Brazil) system. The elastic scattered reaction products with ^{8}Li particles were also detected by Si surface barrier $\Delta E + E$ telescopes in an angular range of 15–35 degrees in the laboratory system, in 5 degree steps mounted on the rotating plate of the chamber. The secondary targets used were self-supporting, pure ^{9}Be, ^{51}V targets of thickness 1.4 mg/cm^2 and 5 mg/cm^2, respectively. The energies measured were 19.6 MeV for ^{9}Be target and 18.5 MeV for ^{51}V target. A gold target of thickness 300 μg/cm^2 was also used. The elastic scattering of ^{8}Li on this gold target was measured in all runs at different angles and used to obtain the overall normalization. The total reaction cross sections were extracted from the elastic scattering analysis for several light weakly

bound systems using the optical model with Woods-Saxon and double-folding–type potentials. Different reduction methods for the total reaction cross-sections have been applied to analyze and compare simultaneously all the systems. The total reaction cross-sections for all systems, and by the two reducing methods used, were found to be similar, irrespective of the projectile being tightly or weakly bound, stable or radioactive, except when halo nuclei were present. In this situation, the total reaction sections were larger than for the others.

Future Outlook

The study using the weakly bound nuclei, radioactive ion beam and halo nuclei has drawn the great attention in the recent years. In the present thesis also it has been focused that the studies on the effect of breakup using the weakly bound projectiles on medium–mass range target is done in a limited manner. For the targets of heavy mass it is known that Coulomb breakup dominates and for lighter ones nuclear breakup predominates. The investigation of the presence of TA, BTA or energy-independent optical potentials through the analysis of elastic-scattering angular distributions is a very difficult task, since the desired manifestation of the optical potential behaviour can only be assessed near and below the barrier energies, where the elastic scattering is predominantly of Rutherford type, and small deviations from it may only be obtained from very precise measurements. Thus more efforts should be put on to investigate the breakup effects using the medium–mass range target with the same weakly bound projectiles.

Moreover a systematic behaviour for the energy dependence of the optical potential in the scattering of ^{7}Li has not been reached so far, since the few systems investigated in the literature (^{27}Al, ^{28}Si, ^{59}Co, ^{138}Ba, ^{144}Sm, ^{208}Pb) show different behaviours. Particularly for medium-heavy targets, there is only one work on the ^{144}Sm target, where nearly energy-independent real and imaginary potentials were observed. For the ^{138}Ba target, different analyses lead to different conclusions for which initial no BTA was observed and then precise corrections made the observance of BTA. So we have made the successful effort by using the same projectile and different medium–mass range target. More such experiments need to be done so as to get the clear – cut view of the reaction mechanisms using such projectile.

Also with the development of radioactive ion beams (RIB), the possibilities to investigate the properties of atomic nuclei and nuclear reactions have open widely. The low-energy reactions of few-nucleon transfer induced by radioactive beams open up new potentials to investigate the cluster structure and to obtain the spectroscopic characteristics of short-lived nuclei. To contribute, the elastic scattering and total reaction cross section have been measured using radioactive ion beam ^{8}Li used on the lighter & medium mass range targets, and successful comparisons of the total reaction cross section with the other systems has been done to extract some fruitful conclusions. This work may be extended for the study of some other reactions mechanism induced by radioactive nuclei such as elastic scattering near the Coulomb barrier, fusion and breakup.