Chapter 6

Conclusion

In the present thesis we have carried out a theoretical investigation on the properties of reactions induced by loosely bound projectiles. To some extent, our work is motivated by the huge amount of experimental data that has become available in the last decade and a half. The properties studied by us are the fusion barrier, fusion cross section, fusion suppression and also the reduced reaction cross section analysis of radioactive systems. In chapter 2, the fusion barrier parameters \((V_B, R_B)\) of thirteen reactions induced by the loosely bound projectiles, \(^6\text{Li}, ^7\text{Li}\) and \(^9\text{Be}\) are studied. For evaluation of the fusion barriers, eight different versions of the proximity potential are employed. The potentials Bass 80 and BW 91 are found to be most effective in reproducing the values of \(V_B\) and \(R_B\), respectively. The parametrized formula \((V_B = 1.44Z_1Z_2(R_B - 0.75)/R_B^2)\) connecting \(V_B\) and \(R_B\) has also been tested for the above reactions, and the formula is found to be extremely effective. For the reaction \(^6\text{Li}+^{152}\text{Sm}\), the deviation of the barrier parameters from the experimental values are quite large. On applying the correction to the Coulomb potential for the deformed target \(^{152}\text{Sm}\), the new values of the barrier parameters are found to be much closer to the empirical values.

In the third chapter we studied the fusion cross section for the reactions \(^6\text{Li}+^{209}\text{Bi}, ^9\text{Be}+^{208}\text{Pb}, ^7\text{Li}+^{209}\text{Bi}\) and \(^6\text{Li}+^{152}\text{Sm}\). Wong’s formula is used for determination
of the fusion cross section, and the barrier parameters needed for use in the Wong's formula are taken from chapter 2. For all the reactions, the fusion cross section is in agreement with the results of the single barrier penetration model (SBPM). We also note that the experimental results are much below the theoretical expectations. This is because of the fact that fusion suppression is dominant in these reactions which takes place due to breakup of the projectile. For the reaction \( ^6\text{Li} + ^{152}\text{Sm} \) we also observe that the fusion cross section for the deformed target case is in much better agreement with the theoretical predictions than in case of spherical target. This proves that target deformation has a great role to play in the study of fusion cross section.

In the fourth chapter we present a semiclassical model for the explanation of fusion suppression. The problem is essentially separated into two parts. In the first part the cutoff impact parameter for fusion is determined, and in the second part we find the fraction of projectiles undergoing breakup within this cutoff impact parameter. The cutoff impact parameter for fusion is obtained through rigorous quantum mechanical concepts as fusion is a quantum mechanical barrier transmission problem having no classical analogue. We applied the classical trajectory method in order to determine the fraction of projectiles undergoing breakup within the cutoff impact parameter for fusion. Studying the numerical solutions, a breakup condition for a trajectory is defined. Then for each impact parameter, the breakup fraction is determined by taking a sample of 50 trajectories. Then, a simple formula for explanation of fusion suppression is proposed, according to which fusion suppression is given by the average of the breakup fractions evaluated at impact parameters ranging from head-on collision up to the cutoff impact parameter. On application of the above formula, we find that there is very good agreement between \( \sigma_{\text{cal}} \) and \( \sigma_{\text{exp}} \) for the three systems \( ^6\text{Li} + ^{209}\text{Bi}, \) \( ^6\text{Li} + ^{152}\text{Sm} \) and \( ^6\text{Li} + ^{144}\text{Sm} \). The agreement of our results with experimental data also suggests that the above barrier breakup of \( ^6\text{Li} \) nucleus in the field of a heavy target nucleus can be fruitfully studied by applying classi-
cal Newtonian laws. This is especially important in view of the fact that quantum mechanical methods (like CDCC), employed for studying breakup, can work only under approximations which may not lead to accurate results under all conditions. Another contribution in this chapter is the development of a semiclassical model of the $^6$Li nucleus. The model is essential for obtaining the initial conditions for solving the classical equations of motion.

In the fifth chapter, we present an analysis of reaction cross section induced by radioactive projectiles ($^6$He, $^8$B and $^7$Be). It is now well known that the reduced reaction cross section (vs reduced energy) shows separate trajectories for tightly bound, loosely bound and radioactive halo systems. Also it has been pointed out that this existence of well-defined paths is due to the separation of the barrier parameters for the three types of systems. In this work we sought an explanation for the shift in the barrier parameters of radioactive halo systems with respect to normal loosely bound systems by using six different nuclear potentials. The calculated shift of the barrier parameters closely matches the experimental shift of the barrier parameters obtained from reduced reaction cross section analysis. This result proves that the separation of the trajectories of the reduced reaction cross section of different systems is contained within the global parametrization of nuclear potentials. For the proton halo system, the shift can only be explained if new values of the radii (for $^{10}B$ and $^8B$) are taken into consideration which is because of the fact that the radius of the halo nucleus ($^8B$) is greater than the normal nucleus ($^{10}B$). For the reactions $^6He + ^{27}Al$ and $^7Be + ^{27}Al$, fitting of the total reaction cross section is done using the modified Wong's formula (MWF) (PRC, 86, 057603). From the quality of the fit, it can be concluded that for halo and loosely bound systems, the modified Wongs' formula (MWF) gives a better reproduction of the experimental reaction cross section than the unmodified Wongs' formula (UWF).

In our opinion, the work presented here has a lot of scope for future research. Many other potentials, like, single-folding, double-folding and Skyrme energy den-
sity, could be used for the evaluation of the barrier parameters \((V_B, R_B)\) of loosely bound systems. It would be interesting to see how they compare with the predictions of the proximity potentials that has been reported here. For the system \(^{6}\text{Li}+^{152}\text{Sm}\), correction of the nuclear potential for the deformed target can also be tried, especially for the potentials Prox 88 and BW 91. For the determination of the fusion cross section above the barrier, improved versions of Wong’s formula (Balantekin’s correction) can be used for accurate determination of the fusion cross section.

Fusion suppression factor for other \(^6\text{Li}\) based reactions can also be studied. Instead of using Wood’s-Saxon potential, other nuclear potentials can also be used in the classical equations of motion. It would be interesting to observe which other nuclear potentials (apart from Wood’s-Saxon) can predict an accurate picture of breakup of the projectile. The model of fusion suppression developed here is a two-dimensional classical trajectory model. The obvious generalization would be a three-dimensional model. It would be interesting to see whether the formula for fusion suppression proposed here for the two-dimensional model (Eq. 4.64) would still be applicable for the three-dimensional model. In the three-dimensional model, the orientation of the projectile is not necessarily confined to a single plane which is the case for the two-dimensional model. Finally, a fully quantum mechanical model of fusion suppression could be attempted in future even though it may be a highly challenging task. For this it would be necessary to develop a fully quantum mechanical version of the model of \(^6\text{Li}\) nucleus that has been proposed here.