Investigation of fusion and transfer reactions using weakly bound projectiles

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The investigation of nuclear reactions induced by the weakly bound stable projectiles ^{6,7}Li and ^{9}Be at near-barrier energies has emerged as one of the most interesting and challenging issues in low-energy nuclear physics, with applications extending to astrophysical interests. These projectiles having low separation energy due to weak binding (^{6}Li:1.47 MeV; ^{7}Li:2.47 MeV; ^{9}Be:1.57 MeV) and clustering (^{6}Li: $\alpha + d$; ^{7}Li: $\alpha + t$; ^{9}Be: $\alpha+\alpha+n$) can breakup easily in the field of nucleus and alter the reaction mechanisms [1, 2]. The suppression of complete fusion (CF), large α production, change in behaviour in optical model potential parameters are some of the highlights using these weakly bound projectiles.

The present thesis work is about the investigation of fusion and transfer reactions using weakly bound projectiles. We have done measurement of fusion and neutron transfer cross sections for ^{7}Li+^{205}Tl system. In addition, we have also performed theoretical coupled channel calculations for the available set of data for ^{9}Be+^{169}Tm,^{181}Ta,^{187}Re as well as ^{6,7}Li+^{124}Sn systems. The details of measurement and the calculations are discussed below.

Fusion cross sections: In the first part, we have measured the complete and incomplete fusion cross sections as well as neutron transfer cross sections for ^{7}Li+^{205}Tl system around Coulomb barrier energies.

The experiment was carried out using Indian National Gamma Array at 14UD BARC-TIFR Pelletron Linear accelerator facility, Mumbai at energies ranging from E_{beam} = 24-40 MeV. Prompt γ-ray transitions in the reaction were detected. The residues populated via CF (^{208,209}Po) and ICF (^{207,208}Bi from α-capture and ^{206,207}Pb from t-capture) channels were identified. The complete details of the measurement are reported in our work [3].

The measured residue cross sections were compared with statistical model calculations performed with the code PACE [4] and a good agreement was observed. The residue cross-sections were then added to get the CF cross sections, which are then compared with 1DBPM and coupled channel calculations performed with CCFULL code [5]. It was observed that at sub-barrier energies, the calculated CF cross sections with the couplings are enhanced compared to the uncoupled calculation. However,at above-barrier energies, the measured values of CF are found to be lower than the calculated ones and suppressed by 26±4% compared to the CCFULL prediction. Similarly, residues from ICF process were identified and cross sections were extracted. The σ_α are found to be smaller compared to σ_t.

Further to rule out the dependence on potential parameters fusion radius R, fusion barrier V_B, curvature $\hbar\omega$, a reduction procedure for fusion data was adopted that completely eliminates the geometrical and static effects of the potential acting between the interacting partners known as Universal Fusion Function (UFF) method. The experimental CF, ICF and TF functions and the incident energy are reduced to a dimensionless equation called the fusion function $F(x)$ and dimensionless variable x. Any deviation of the measured FF from the universal fusion function (UFF) defined by $F_0(x)$= ln[1 + $exp(2\pi x)$ may be due to the breakup of the incident projectile. The available data with ^{7}Li projectile was found to follow universal behaviour in CF, ICF and TF cross sections. The results are reported in Ref. [3].

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Neutron transfer: In the second part, we have performed the coupled channel calculations for the neutron transfer data available in ^{9}Be+^{169}Tm,^{181}Ta,^{187}Re [6], ^{7}Li+^{205}Tl [7] and ^{6,7}Li+^{124}Sn systems [8, 9] and also studied the significance of neutron transfer in the reaction mechanism [11].

The measured one neutron stripping cross sections for these systems have been compared with the coupled channel calculations performed using the code FRESCO [10]. Global set of optical model potential parameters were used for both entrance and exit channels. The calculations found to reproduce the data for all the systems studied [8, 9, 11]. In addition, the total sum of measured fusion (CF and ICF), one neutron stripping and calculated non-capture breakup cross sections was also found to reproduce the estimated reaction cross sections. Further the percentage fraction of CF, ICF, one neutron stripping, and NCBU cross section over reaction cross sections showed the dominance of neutron transfer and NCBU at below barrier energies while CF and ICF processes show more contribution at above barrier energies. In addition, the systematics of neutron transfer cross sections was also made for the first time. The results are reported in Refs. [8, 9, 11]

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References

[1] L. F. Canto *et al.*, Phys. Rep. 596, 1 (2015).
[2] V. Jha, V. V. Parkar, and S. Kailas, Phys. Rep. 845, 1 (2020).
[3] V. V. Parkar *et al.*, Phys. Rev. C 109, 014610 (2024).
[4] A. Gavron, Phys. Rev. C 21, 230 (1980).
[5] K. Hagino, N. Rowley, and A. T. Kruppa, Comput. Phys. Commun. 123, 143 (1999).
[6] Y. D. Fang *et al.*, Phys. Rev. C 93, 034615 (2016).
[7] Prasanna M. *et al.*, Proc. of DAE Symp. on Nucl. Phys. 66, 381 (2022).
[8] V. V. Parkar, A. Parmar, Prasanna M., V. Jha, S. Kailas, Phys. Rev. C 107, 024602 (2023).
[9] V. V. Parkar, A. Parmar, Prasanna M., V. Jha, S. Kailas, Phys. Rev. C 104, 054603 (2021).
[10] Ian J. Thompson, Comput. Phys. Rep. 7, 167 (1988).
[11] Prasanna M., V. V. Parkar, V. Jha, A. Parmar, Bhushan. A. Kanagalekar, and B. G. Hegde Nucl. Phys. A 1029 (2023) 122570