Role of Neutron Transfer in Sub-barrier Fusion

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In heavy-ion induced reactions, fusion cross-sections at sub-barrier energies are significantly enhanced as compared to the predictions of one-dimensional barrier penetration model (1-D BPM) [1, 2], which has been interpreted in terms of static deformations, couplings of in-elastic excitations, and non-fusion channels, especially the positive Q-value neutron transfer (PQNT) channels. However, the interplay and quantitative contribution of the factors which influence the sub-barrier fusion enhancement are not yet completely understood. Further, in some experimental measurements, the fusion EF steeply fall off as compared to the predictions of standard coupled-channels calculations, whereas in other cases the enhancement is observed [3]. Aiming to investigate the role of different couplings, PQNT channels, and to study the behaviour of EF at the deep sub-barrier energies, fusion cross-sections have been measured for ^{35,37}Cl+^{130}Te systems from 10 % below to 15 % above the barrier. This is particularly interesting because ^{35}Cl+^{130}Te system has six PQNT channels with respect to none in ^{37}Cl+^{130}Te system. Further, these systems are suitable to probe the shell effect as the target is common and projectiles are different in terms of the shell structure. The outermost shell ($1d_{3/2}$) of ^{35}Cl is half-filled by neutrons and ^{37}Cl case, it is fully filled.

Experiments have been performed at the Inter-University Accelerator Centre (IUAC), New Delhi, India using a recoil mass separator, Heavy-Ion Reaction Analyser (HIRA)[5]. ^{35,37}Cl beams obtained from 15UD Pelletron accelerator were bombarded on ^{130}Te target [4]. The fusion cross-sections have been determined at different energies by measuring ERs. Since the time of flight of ERs is about 1.5 μs around the barrier the pulsed beams of 2 μs were used to get the clear separation between projectile-like particles and ERs.

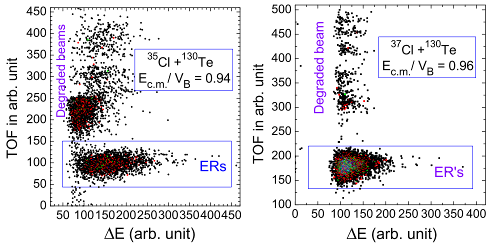

FIG. 1: ΔE-TOF spectra for ^{35,37}Cl+^{130}Te systems, shows that the ERs are separated clearly from degraded beam like-particles.

The ERs were identified by making an electronic gate between TOF and corresponding energy loss suffered by the ERs in cathode of MWPC (ΔE). Two ΔE-TOF spectra for ^{35,37}Cl+^{130}Te systems are given in Fig.1, which display the clear separation between ERs and degraded beam like particles [5].

The fusion cross-sections have been measured down to 1 μb at 10 % below the barrier for ^{37}Cl+^{130}Te system, and down to 0.034 mb for ^{35}Cl+^{130}Te system. To gain insights into the role of neutron transfer in sub-barrier fusion, the reduced fusion EFs of ^{35}Cl+^{130}Te and ^{37}Cl+^{130}Te system have been compared. The fusion cross-section ($\sigma_{\rm fus}$) and centre-of-mass energy ($E_{\rm c.m.}$) has been normalised as given in the Fig. 2 to incorporate the effect of radius and barrier height. As shown in this figure, the fusion EF of ^{35}Cl+^{130}Te system is found to be substantially higher than that of ^{37}Cl+^{130}Te system in sub-barrier energy region, hinting towards the role of neutron transfer in sub-barrier fusion, which is further confirmed from the coupled-channels calculations [5, 6]. Addition to that, at the time of interaction of ^{35}Cl and ^{130}Te, ^{35}Cl

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needs two extra neutrons in its outermost shell to be stable. Hence, neutrons flow establishes from ^{130}Te to ^{35}Cl due to configuration mixing between the interacting partners, and consequently, the projectile fuses with the target instead of exchanging neutrons. In light of neutron flow model [7], it may be inferred that the ^{35}Cl has more fusion probability as compared to ^{37}Cl with ^{130}Te nucleus. Further, both ^{35}Cl and ^{37}Cl projectiles are in oppositely deformed with deformation parameter $\approx$ -0.24 and $\approx$ +0.11, respectively, and the excited states of the projectiles are of the nearly same order of magnitude. The oblate shape of ^{35}Cl may reduce the effective barrier for fusion as compared to ^{37}Cl, leading to the enhanced fusion cross-section for ^{35}Cl+^{130}Te system in the sub-barrier region [6].

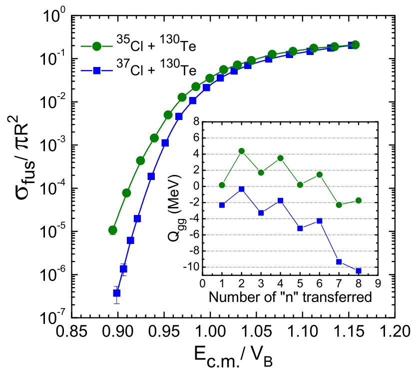

FIG. 2: The reduced fusion excitation functions of ^{35}Cl+^{130}Te and for ^{37}Cl+^{130}Te system. Inset shows the Q - values of different neutron transfer channels for both the systems.

The EF of both systems has been analyzed in the framework of coupled-channels calculations to understand the effect of static deformation, and PQNT channels [5, 6]. The experimentally measured fusion cross-sections have been found to be substantially enhanced at sub-barrier energies as compared to the prediction of 1-d BPM. To understand the observed enhancement, the calculations have been performed for each system by including the different inelastic excitations of projectile and target. It has been observed that the coupling of low-lying excited states of interacting partners reproduces the fusion EF of ^{37}Cl+^{130}Te system satisfactorily. However, the inclusion of couplings underpredict the measured fusion cross-sections of ^{35}Cl+^{130}Te system at sub-barrier energies. This suggests that the inclusion of deformations and inelastic excitations in the calculations is not sufficient to explain the sub-barrier fusion enhancement. To interpret the EF of ^{35}Cl+^{130}Te system, +2n transfer channel has been included in the calculations, which reproduces the fusion EF fairly well at sub-barrier energies [6].

The fusion barrier distribution, the astrophysical S-factor and the logarithmic derivative, L(E)-factor have been extracted by the interpreting the measured EF of ^{37}Cl+^{130}Te system. The experimental fusion barrier distribution is found to be broad, and mainly splited into two peaks around the one-dimensional barrier, which is due to the coupling of low-lying inelastic excitations of interacting partners. The astrophysical S-factor and the L(E)-factor indicates the absence of fusion hindrance down to 1 μb cross-section in ^{37}Cl+^{130}Te system [5]. The details results and discussion will be presented during the conference.

I acknowledge to MHRD for fellowship, DST-SERB for the international travel grant, IUAC for the experimental facilities, and NuStaR lab. of Physics Department at IIT Ropar for the suitable environment for research.

References

[1] B. B. Back *et al.,* Rev. Mod. Phys. **86**, 317 (2014).

[2] M. Dasgupta *et al.,* Phys. Rev. Lett. **99**, 192701 (2007).

[3] C. L. Jiang *et al.,* Phys. Rev. Lett. **93**, 012701 (2004).

[4] Rudra N. Sahoo *et al.,* Nucl. Instrum. Methods A **935**, 103-109 (2019).

[5] Rudra N. Sahoo *et al.,* Phys. Rev. C **99**, 024607 (2019), references theirin.

[6] Rudra N. Sahoo *et al.,* submitted to Phys. Rev. C.

[7] P. H. Stelson, Phys. Lett. B **205**, 190 (1988).