Effect of target deformation and projectile breakup in complete fusion of ^{6}Li+^{152}Sm

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Nuclear reaction induced by weakly bound (stable or radioactive) nuclei is a subject of current experimental and theoretical interest [1,2]. Due to their small binding energy compared to strongly bound projectiles, there can be many new reaction modes involving final products in the continuum, e.g. break up and unconventional transfer channels. There are contradictory results and predictions about the enhancement or suppression of the fusion cross section σ_{fus} , over the predictions of single barrier fusion model, around the Coulomb barrier. Measurements of fusion cross section involving loosely bound projectile ^{6}Li [3,4] and ^{9}Be [5,6] exist with different conclusion about the enhancement or suppression of fusion cross section. Recently we have measured the fusion cross section for ^{6}Li + ^{144}Sm [7], where it has been found that there is an enhancement of fusion cross section below the barrier in comparison with single BPM calculation, where as there is an overall suppression in fusion cross section as compared to CCFULL calculation in the entire energy range measured. A systematics of the fusion cross section for the systems involving loosely bound projectiles showed that the suppression factor increases with the Z of the target [7]. However, it would be interesting to see how the target deformation play a role on fusion cross section, keeping the Z of a target same. With this motivation, we chose a deformed target, ^{152}Sm, with β_2 =0.24 to compare with the results of ^{144}Sm which is a spherical target. It will also be interesting to see effect of target deformation (enhancement) versus projectile breakup (suppression) specially at sub-barrier energy.

The fusion cross sections for ^{6}Li + ^{152}Sm reaction have been measured at energies near and above the barrier using 14UD BARC-TIFR pelletron facility at Mumbai. The enriched (98%) ^{152}Sm targets with thickness ~ 320 – 592 μg/cm^2 were prepared by electro-deposition method on Al backing of thickness ~ 3 mg/cm^2. The thickness of the targets was measured by the Rutherford backscattering method using 60 MeV, ^{16}O beam.

Each of the 12 targets was irradiated for 4 to 5 hours by ^{6}Li beam with energy varying from 20 to 40MeV in steps of 1 MeV around the barrier and in steps of 4 MeV above the barrier. The beam current was ~ 80 nA . The reaction products were stopped in the target +Al backing which is acting like a catcher foil, and identified by detecting characteristic gamma rays by off line measurement using HPGe detector. When ^{6}Li fuses with the target nucleus (^{6}Li +^{152}Sm), it produces the excited compound nucleus ^{158}Tb*. After 3n evaporation, it produces the evaporation residue (ER) ^{155}Tb* (g.s) with half life 5.32d, similarly after emitting 2n and 4n it produces the residues ^{156}Tb* and ^{154}Tb* respectively, among which ^{154}Tb has two metastable state (^{154}Tb^m, $t_{½}$ ~ 9.4h. ^{154}Tb^m, $t_{½}$ ~ 22.7h.) with ground state (^{154}Tb^g, $t_{1/2}$ ~ 21.5 h), which decay to Gd nuclei after electron capture. Figure 1[a] shows the ER cross sections for the individual channels at different Ecm.

Statistical model (SM) calculations are performed using the code PACE [8] with default potential parameter. For energies below the barrier the SM calculations were carried out by feeding the ℓ distribution obtained from external coupled channel (CCFULL) calculation. Since the combined contribution of 3n and 4n channels were found to be ~ 80-90% in the energy range (20-40 MeV) of our measurement, the complete fusion cross sections were obtained by normalizing these values as per the procedure adopted in [7].

The measured excitation function for complete fusion has been shown as filled circles in Fig.1[b]. Open circles represent the complete fusion cross sections for ^{6}Li + ^{144}Sm [7]. It can be seen that CF for the present system is similar at above barrier energies, but they are much larger at sub-barrier energies as compared to ^{6}Li + ^{144}Sm. Experimental fusion barrier distribution was also obtained and shown in the inset of Fig.1[b]. Coupled channel calculations are performed by using the code CCFULL [9] with potential parameters that reproduce the average experimental fusion barrier. The doted line in Fig.1 [b] corresponds to the fusion by single BPM calculation and the dashed line corresponds to the coupled results with only target rotational states (β_2=0.24, E_x=0.1217 MeV, β_4=0.065).
The solid line corresponds to the coupling of the projectile ground state (1^+) and the unbound first excited state (3^+, 2.186) with β_{00} (β_2 for the ground state reorientation) = -0.079, β_{01} (β_2 for the transition between the ground and the first excited states) = β_{11} (β_2 for the reorientation of the 1st excited state) =1.51 in addition to the target excitation. Coupling to the breakup channel is not included. It can be seen that the calculated values of CF with full couplings are much higher than the measured ones at above barrier energies, and they are under predicted at sub-barrier energies. Since the effect of the coupling is negligible in the above barrier region, one can definitely conclude that the CF is suppressed at this energy range, and this may be a direct consequence of the loss of incident flux due to the projectile breakup. However, at sub-barrier region, although there seems to have an enhancement compared to the present model calculation, one cannot have a definite conclusion the effect of channel coupling is model dependent.

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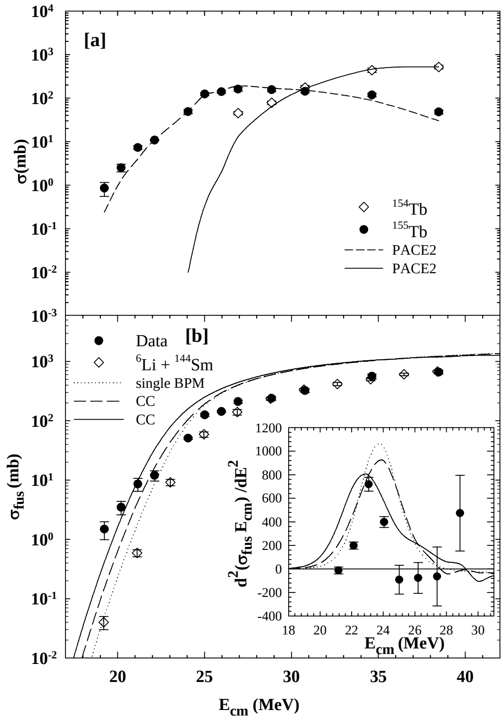

FiG. 1: [a] ER cross section for different nuclei, filled circle for ^{155}Tb, open diamond for ^{154}Tb.
[b] Fusion cross section for ^{6}Li + ^{144}Sm [7], filled circle for ^{6}Li + ^{152}Sm (present), dotted line for single BPM, dash line CCFULL with target in rotational coupling and solid line for target coupling including projectile unbound state**.**

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