Complete fusion of weakly bound ^{7}Li with ^{144}Sm

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Introduction

Nuclear reaction involving weakly bound (stable or radioactive) projectile is a subject of current experimental and theoretical interest [1,2]. Due to their small binding energy there can be many new reaction modes involving final products in the continuum, e.g. breakup and 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. Fusion cross section for ^{6}Li + ^{144}Sm reaction, that we have measured recently [3], was found to be enhanced compared to the prediction by single barrier penetration (BPM) model calculation, but there was an overall suppression of ~ 32% in fusion cross section as compared to CCFULL calculations (with full coupling) in the entire energy range measured. A systematics of the fusion cross sections for the systems involving loosely bound projectiles [3] showed that the suppression factor increases with the Z of the target and decreases with the breakup threshold of the projectile. So, it would be interesting to study the fusion reaction for ^{7}Li+^{144}Sm and compare with ^{6}Li+^{144}Sm to test the suppression factor dependence on breakup threshold in above systematics. Since the projectile (^{7}Li→ α+t) having a higher breakup threshold (2.478 MeV) than ^{6}Li (1.478 MeV) and the target is same, it is expected that the complete fusion (CF) suppression factor would be less compared to that of ^{6}Li+^{144}Sm.

Measurements

The fusion cross sections for ^{7}Li + ^{144}Sm reaction have been measured at energies near and above the barrier using 14UD BARC-TIFR pelletron facility at Mumbai. The ^{144}Sm targets with thickness ~ 450 – 678 μg/cm^{2} were prepared by electro-deposition method on Al backing of thickness ~ 2.2 mg/cm^{2}. Each of the 14 targets was irradiated for 4 to 8 hours by ^{7}Li beam with energy varying from 22 to 40MeV in steps of 1 MeV around the barrier and in steps of 2 MeV above the barrier. The beam current was ~ 40 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 ^{7}Li fuses with the target nucleus (^{7}Li +^{144}Sm), it produces the excited compound nucleus ^{151}Tb*. After 2n evaporation, it produces the evaporation residue (ER) ^{149}Tb* (g.s) with half life 4.118h and ^{149}Tb* (m.s) with $t_{1/2}$ ~ 4.16m. Similarly after emitting 3n it produces the residues ^{148}Tb* having metastable state (^{148}Tb^{m}, $t_{½}$ ~ 2.2m) and ground state (^{148}Tb^{g}, $t_{1/2}$ ~ 60.0 m), which decay to Gd nuclei after electron capture. Fig. 1(a) shows the ER cross sections for the individual channels at different $E_{c.m.}$.

Coupled channels calculations

Statistical model (SM) calculations are performed using the code PACE [4] with default potential parameters. For energies below the barrier the SM calculations were carried out by feeding the ℓ distributions obtained from external coupled channels calculations. Since the combined contribution of 3n and 2n channels were found to be ~ 80-90% in the energy range (22-40 MeV) of our measurement, the complete fusion cross sections were obtained by normalizing these values as per the procedure adopted in [3].

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 [3]. It can be seen that CF for the present system is almost 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 Fig. 1(c). Coupled channels calculations are performed by using the code CCFULL [5] with potential parameters that reproduce the average experimental fusion barrier (~25.4 MeV). The dotted line in Fig. 1 (b) corresponds to the fusion by single BPM calculation and the dashed line corresponds to the results with full couplings which includes the coupling of the projectile ground state ($3/2^-$) and the unbound first excited state ($1/2^-$, 0.4776 MeV) with β_{00} (β_2 for the ground state reorientation) = 1.189, 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) =1.24 in addition to the target vibrational state (3^-, β_2=0.23, E_x=1.81 MeV) coupling to the breakup channel is not included. It can be seen that the calculated values of CF with full couplings are higher than the measured ones at above barrier energies, and they are under predicted at sub-barrier energies. Multiplying the coupled values with a factor of 0.80 reasonably reproduces the data at above energies, but not at sub-barrier energies. Since the effect of coupling on fusion at energies above the barrier is negligible, one can conclude that the CF is suppressed by ~ 20 % in this region and this may be a direct consequence of the loss of incident flux due to the projectile breakup. This suppression factor (~20%) is found to be less than the ^{6}Li case (~32%), and it agrees with the systematics [3]. However, at sub-barrier region, it is interesting to find that, unlike ^{6}Li+^{144}Sm, the CF is enhanced compared to the present model calculation. The reason behind such an observation is not clear though, which needs further investigation.

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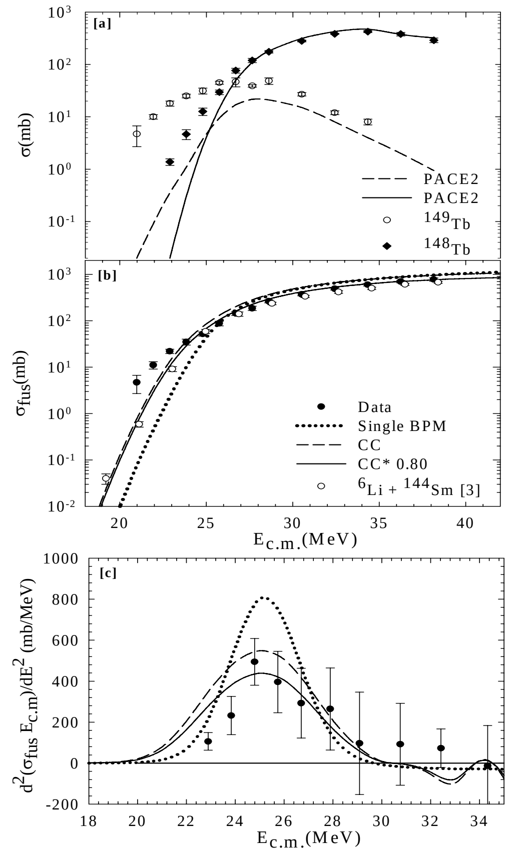

Fig. 1: (a) ER cross sections for ^{148}Tb (filled circle) and ^{149}Tb (open circle). (b) Fusion cross section for ^{7}Li+^{144}Sm (filled circles) and ^{6}Li + ^{144}Sm [3] (open circles). Results of CCFULL calculations for single BPM and full couplings are represented by dotted and dashed line respectively**.** **S**olid line corresponds to the CCFULL results multiplied by a factor of 0.80. (c) Corresponding barrier distributions.

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