Disentangling effects of breakup coupling and incomplete fusion in ^{6}Li+^{232}Th reaction

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Introduction

Several experimental and theoretical reaction studies involving weakly bound nuclei have been performed in recent years, however there is still no consensus on the behaviour of the fusion cross sections at energies around the Coulomb barrier in such cases [1]. Both enhancement and suppression of the fusion cross sections have been predicted from the calculations and similar conclusions have been drawn from the measurements. These observations are often ascribed to the dynamic coupling effects arising due to the breakup and transfer processes. A component of fusion that is very important but quite difficult to evaluate is the incomplete fusion (ICF), in which only a part of the nucleus fuses with the target. ICF occurs together with the usual complete fusion (CF), in which the whole projectile fuses or all the projectile fragments after breakup fuse with the target nucleus. The ICF leads to the flux removal from the fusion channel and its calculation is essential for a comprehensive description of the fusion process.

In the present work, a recently developed method of calculating the ICF cross section (σ_{ICF}) [2] is used in a novel way to disentangle the ICF effect on the fusion process from those due to breakup couplings. The total fusion cross section σ_{TF} and σ_{ICF} for the ^{6}Li+^{232}Th system are calculated at energies above and below the Coulomb barrier, where the measured fusion-fission data is available [3, 4]. For the actinide targets, the fission cross section σ_f can be taken as equivalent to σ_{TF} with good accuracy, where the latter

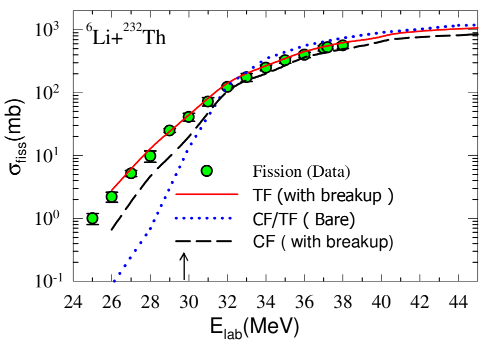

FIG. 1: TF and CF cross sections at energies around the Coulomb barrier for the ^{6}Li + ^{232}Th system. The uncoupled calculations are shown by the dotted line (same for CF and TF) while the coupled calculations for the CF and TF cross sections are shown by the dashed and solid line. The measured data for the fission cross sections are taken from Ref. [3]

is expressed as sum of CF cross section σ_{CF} and σ_{ICF}.

Calculation

The calculations for the σ_{ICF} and σ_{TF} are performed using the Continuum Discretized Coupled Channels (CDCC) framework. A two body $\alpha+d$ cluster structure for the ^{6}Li is assumed. The discretization of the continuum and channel coupling scheme is similar to that used in Ref. [5]. The diagonal and the coupling interactions were calculated using the cluster-folding method from the pair of input optical potentials α - ^{232}Th (V_α) and d - ^{232}Th (V_d). The total fusion in the present three body CDCC approach can be calculated by employing separate short range imaginary potentials, $W_{\alpha-T}$ and W_{d-T} between both projectile fragments and the target with same pa-

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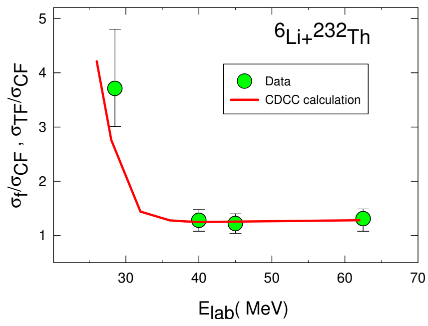

FIG. 2: Measured ratio of fission cross section σ_f and σ_{CF} taken from Ref. [4] is compared with the calculated ratio of σ_{TF} and σ_{CF}

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rameters W_0 = 25 MeV, r_0 = 1.0 fm , and a = 0.2 fm. Use of the short range imaginary part of the cluster target potentials takes into account the separate or simultaneous fusion of both the projectile fragments α and d.

Results

The absorption cross sections obtained from the CDCC calculations for the σ_{TF} without and with the inclusion of breakup channels at different energies are presented by solid and dotted lines respectively, in Fig. 1. The σ_{TF} is compared with the experimental data for the total fusion-fission cross sections shown by the solid circles Fig. 1, which are taken from Ref. [3]. The calculation with the full breakup couplings, which also includes the ICF contribution gives a good description of the data. The calculations show a significant enhancement of the fusion cross section below the barrier due to the inclusion of breakup channels, while it leads to small suppression of the TF cross section at energies above the barrier. By subtracting the contribution of ICF component σ_{ICF} from the TF cross sections an estimate of CF cross sections can be obtained. The extracted CF cross sections are shown by the dashed line in Fig. 1. In the calculations where the breakup channels are not included, the CF and TF cross sections correspond to the same quantity as shown by the dotted lines in Fig. 1. It can be concluded that breakup coupling effects give an enhancement of fusion cross sections at lower energies, which is further increased if the ICF is included. In contrast, at higher energies the suppression seen in CF is due to dynamic breakup coupling effects, which is reduced if one takes into account the ICF.

The measured ratios $R_f = \sigma_f \ / \ \sigma_{CF}$ at energies below and above the Coulomb barrier taken from Ref. [4] are compared with the calculated ratio of σ_{TF} to σ_{CF} as shown in Fig. 2. The large value of the measured ratio R_f at energies below the Coulomb barrier are explained by the calculations, which show the increasing dominance of the ICF processes as the lower energies are approached. At energies above the Coulomb barrier the ratio R_f does not vary much and a constant suppression of σ_{CF} with respect to σ_{TF} is obtained. The magnitude of this suppression factor ∼(0.7-0.8) is commensurate with the suppression factors obtained in various experimental studies of fusion process involving the weakly bound nuclei [5].

In conclusion, the effects of breakup couplings and ICF contribution on the fusion process has been studied using the fusion-fission data for the ^{6}Li + ^{232}Th system. The calculations show a significant enhancement of the CF cross sections at below barrier energies and a large suppression of cross sections at above barrier energies due to coupling of the breakup channel. The enhancement below the barrier is increased and the suppression above the barrier is reduced when ICF contribution is included. The ICF cross sections are found to have dominant contribution in TF cross section at energies below the Coulomb barrier.

References

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