Role of continuum couplings in the fusion of ^{15}C with ^{232}Th nucleus

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Introduction

The fusion near the Coulomb barrier involving neutron halo nuclei have received widespread attention in recent times. Due to weak binding of the valence neutrons there is an increased importance of the breakup process. There is a long-standing question of whether the fusion of nuclei involving weakly bound particles is enhanced or suppressed at low energies owing to coupling effects of the breakup channels. The Continuum Discretized Coupled Channel (CDCC) formalism presents an effective method to take into account the coupling effects of breakup. However, the calculations of fusion cross sections in the CDCC calculations and its efficacy in explaining the low energy experimental fusion data is not so well established. The fusion cross sections in the CDCC framework can be calculated as the absorption of the flux from the coupled channels set by employing a short-ranged imaginary part in the potentials of projectile fragment with the target [1, 2].

In the measurement of the fusion-fission cross section of the ^{15}C + ^{232}Th system [3], the measured values are found to be enhanced by a factor of 5 in comparison to those for ^{12,13,14}C + ^{232}Th systems, at the energies below the Coulomb barrier. This observed enhancement is found to be at variance with the theoretical calculations reported in Ref. [4] and also could not be ascribed due to transfer induced fission. The ground state of ^{15}C can be described as a $2s_{1/2}$ neutron coupled to a ^{14}C core with a separation energy of 1.218 MeV and a spectroscopic factor of 1. In the present work, we have performed the CDCC calculations to estimate the fusion cross sections for the ^{15}C + ^{232}Th system assuming a two-body ^{14}C + n cluster structure for the ^{15}C nucleus. We investigate the coupling effects of the breakup on fusion process at energies around the Coulomb barrier and evaluate the effect of absorptive potentials employed for calculations.

Coupled channels calculations

The breakup of the projectile is treated as inelastic excitations for different partial waves in the continuum (nonresonant and resonant) that are induced by both the Coulomb and nuclear part of the projectile fragments-target interactions. The continuum above the one neutron separation energy of 1.218 MeV is discretized into equi-spaced momentum bins and the continuum up to maximum energy of 10 MeV has been included in the calculations. The coupled equations including the effect of breakup continuum are solved using the code FRESCO [5]. We have included s-, p-, d- and f -waves in the continuum and included all transitions of multipolarity 0, 1, 2 and 3.

The interaction potentials between ^{15}C and ^{232}Th were obtained by folding the fragment target potentials ^{14}C + ^{232}Th and n + ^{232}Th. The real part of the potentials are the Akuz -Winther potentials [6] for $V_{^{14}C-T}$ and the global potentials of Ref. [7] for V_{n-T}. For the imaginary part, we make two different selections and these are referred as CDCCa and CDCCb model calculations. In the CDCCa model, the short -range imaginary potentials of Volume Woods-Saxon shape with parameters W_0 = 40 MeV, r_w = 1.0 and a_w = 0.4 fm are used. In addition, same imaginary potential $W_{^{15}C-T}$ is also included in the centre of mass coordinates between the projectile and the target nucleus. In the CDCCb model the

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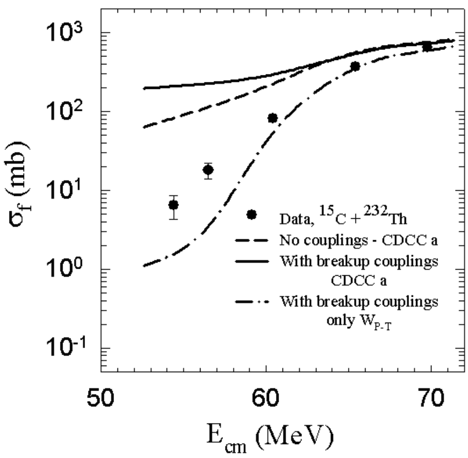

FIG. 1: Calculated ^{15}C + ^{232}Th fusion cross sections using the CDCCa method compared to measured data from Ref. [3]

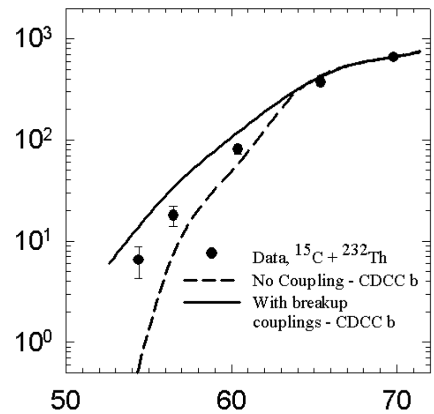

FIG. 2: Calculated ^{15}C + ^{232}Th fusion cross sections using the CDCCb method compared to measured data from Ref. [3]

W$_{n-T}$ is replaced by a shallow surface Woods-Saxon potential W_d with a energy dependence.

Results and Conclusions

The calculated fusion cross sections for ^{15}C + ^{232}Th system at energies around the Coulomb barrier with the CDCCa and CDCCb model are shown in Fig.1 and Fig.2, respectively, along with the measured data [3]. In Fig.1 we show the calculations with no coupling and the effect due to inclusion of the continuum couplings by dashed and solid lines respectively. A large enhancement due to coupling effects of one neutron breakup continuum is observed in the fusion cross sections at energies below the Coulomb barrier ($V_B = 60.5$ MeV) . However, the calculations overpredict the data by a large factor. We also show calculations by dashed-dotted lines in Fig.1, when only the imaginary potential in the centre of mass coordinates between the projectile and the target nucleus $W_{^{15}C-T}$ is used in the calculations and fragment-target imaginary potentials are not included. The reduction of cross sections at low energies in these calculations correspond to events, where one of the fragments of ^{15}C is captured, but the c.m. of the projectile does not reach the absorption (fusion) region. The CDCCb model calculations as shown in Fig.2 give a reasonable description of the measured data and serves as an apprpriate method of calculation of fusion calculations within the CDCC framework.

In summary, we find that the coupling effects of the breakup channels is found to be quite significant in the neutron-rich nuclei at energies below the Coulomb barrier. An energy dependent shallow imaginary potential for the absorptive n + ^{232}Th interaction gives a good description of data.

References

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