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Effect of Neutron Transfer in the Fusion Process Near and Below the Coulomb Barrier

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Abstract. Near-barrier and sub-barrier fusion of weakly bound neutron-rich isotopes of lithium is explored within the empirical channel coupling model. Several combinations of colliding nuclei are proposed, for which strong enhancement of the sub-barrier fusion is predicted owing to coupling with neutron transfer channels.

Keywords: fusion reactions, neutron transfer, empirical channel coupling model
PACS: 24.10.-i, 25.60.-t, 25.70.-z, 25.70.Jj

During the last years, fusion reactions with light weakly bound nuclei have been of increased interest from experimental and theoretical point of view [1]. Fusion enhancement below the Coulomb barrier is one of the most attractive phenomena. The sub-barrier fusion enhancement caused by coupling with vibrational and rotational collective excitations is well studied experimentally and can be described within quantum coupled-channel approach (QCC). Additional increase of the sub-barrier fusion cross sections may arise owing to neutron transfer with positive Q-values. Theoretical analysis of the role of weakly bound nucleons in the process of sub-barrier fusion is very complicated, because it requires a simultaneous account for the break-up, neutron transfer, inelastic and complete fusion channels within one model. The main goal of this paper is an application of empirical channel coupling approach (ECC) [2] to the analysis of the sub-barrier fusion of light nuclei (such as ^{6,9,11}Li) with stable nuclei taking into account neutron rearrangements with positive Q-value. In this model the penetrability of the Coulomb barrier is calculated using the concept of barrier distribution arising due to the multi-dimensional character of the real nucleus-nucleus interaction potential [2]

$$\widetilde{T}_l^{HW}(B;E) = \int f(B) \frac{1}{N_{tr}} \sum_k \int_{-E}^{Q_{gg}(k)} \alpha_k(E,l,Q)\, T_l^{HW}(B;E+Q)\, dQ dB, \qquad (1)$$

where the penetrability of the parabolic barrier T_l^{HW} is defined by the Hill-Wheeler formula [3], E is the center of mass energy, $f(B)$ is the normalized barrier distribution function, $Q_{gg}(k)$ and $\alpha_k(E,l,Q)$ are the Q-values and the probabilities for the transfer of k neutrons, $1/N_{tr}$ is the normalization constant. The calculations are performed taking into account transfers up to 4 neutrons.

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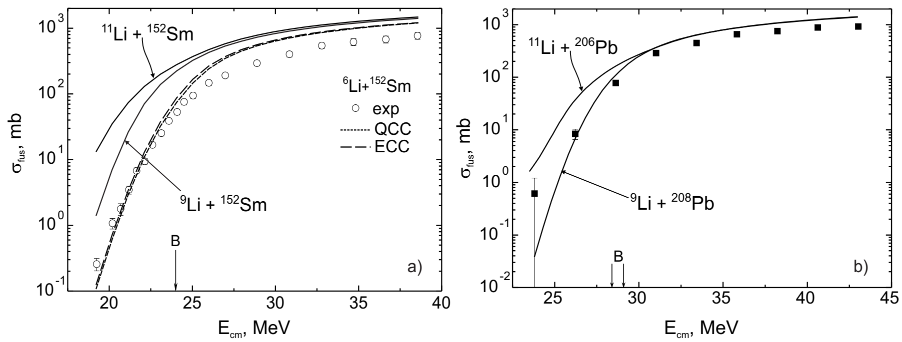

FIGURE 1. Fusion excitation functions for: a) ^{6,9,11}Li +^{152}Sm; b)^{11}Li+^{206}Pb and ^{9}Li +^{208}Pb.

In the case of ^{6}Li +^{152}Sm fusion the only positive and rather small Q_{gg} value (0.204 MeV) corresponds to one neutron transfer and, consequently, neutron exchange should not visibly influence the sub-barrier fusion cross section. In Fig.1 (a) the results of the QCC calculations (short-dashed curve) are compared with the experimental data [4]. The fusion cross section obtained within ECC approach is shown by short-dash curve. It is in good agreement both with QCC and experimental data at sub-barrier energies. The overestimation of σ_{fus} at above-barrier energies is attributed usually to the break-up channels. The break-up channels are not included in our calculations. The predictions of fusion cross sections for ^{9,11}Li +^{152}Sm are shown in 1(a). For the ^{9}Li +^{152}Sm reactions $Q(1n) = +1.8$ MeV, $Q(2n) = +7.74$ MeV, $Q(3n) = +6.3$ MeV, $Q(4n) = +7.87$ MeV and for the ^{11}Li +^{152}Sm reactions $Q(1n) = +5.54$ MeV, $Q(2n) = +13.54$ MeV, $Q(3n) = +15.28$ MeV, $Q(4n) = +20.49$ MeV. As one expected, the larger the positive Q values the higher the sub-barrier fusion probabilities.

Comparison of the fusion cross sections for the reactions ^{11}Li+^{206}Pb and ^{9}Li +^{208}Pb, leading to the same compound nucleus, is shown in 1(b). The calculations for ^{9}Li +^{208}Pb agree quite well with the experimental data [5] except one point, measured with large uncertainty. For the ^{11}Li+^{206}Pb reactions there are intermediate neutron transfer channels with very large positive Q-value: $Q(1n) = +6.4$ MeV, $Q(2n) = +13.8$ MeV, $Q(3n) = +13.7$ MeV, $Q(4n) = +16.8$ MeV. This is leads to enhancement of the sub-barrier fusion cross section for this projectile-target combination by about two order of magnitude as compared with ^{9}Li fusion reaction at 5 MeV below the barrier.

Experimental study of the ^{11}Li induced fusion reactions in comparison to the reactions with lighter lithium isotopes may proof the conclusions performed above.

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