ONSET OF BINARY PROCESSES: A NEW OBSERVABLE FOR THE IN-MEDIUM *NN* CROSS SECTION*

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The transition from the fusion mechanism to binary processes in central heavy-ion collisions is investigated within the Landau-Vlasov semiclassical transport model. The threshold energy of the binary mechanism displays a regular dependence on the value of the nucleon-nucleon cross section and could be a right observable to determine its value in nuclear medium.

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It is generally admitted that the one-body microscopic transport equation complemented with the two-body correction term (Boltzmann's collision integral) correctly describes the bulk properties of heavy-ion collisions at intermediate energies. It is, however, unclear whether for the nucleon-nucleon (NN) cross section σ_{NN} entering into the collision integral one should take its value σ^f_{NN} for the scattering of free nucleons or account for possible in-medium effects on the value of σ_{NN}. Although the role of in-medium effects in finite nuclei is not yet completely understood [1], one expects that, by analogy to the results of infinite-nuclear-matter studies, one has to correct σ_{NN} [2]. There is obvious interest in an observable that would display a regular and sensible dependence on σ_{NN}.

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On the other hand, around the Fermi energy the heavy-ion reaction cross section is strongly dominated by binary mechanism (BM) [3]: independently of the reaction centrality, the two massive fragments, the quasiprojectile and the quasitarget, appear in the exit channel. The Landau-Vlasov (LV) semiclassical simulation has also predicted the binary character of these reactions [4]. Owing to one-body dissipative effects the low-energy central collisions lead to fusion (a single cold residue in the exit channel). Using the LV model with the nonlocal effective Gogny interaction D1-G1 (the incompressibility modulus K_{∞}=228 MeV and the effective mass m^{*}/m=0.67) [5] we extensively study the transition region between fusion and BM by simulating central collisions of several symmetric systems. The binary channel opens for all studied systems ($A_{\rm sys} < 200$).

In this paper we focus mainly on the light Ar+Ar system as it has recently been studied by the INDRA collaboration [6,7]. Figure 1 shows the simulation results for the Ar+Ar head-on collisions at two incident energies: 29 MeV/nucleon (left column) and 30 MeV/nucleon (right column). At 29 MeV/nucleon the system fuses although a large deformation of dinuclear type persists for a long period. This deformation, already present at lower energies, develops with energy and at 30 MeV/nucleon, the binary threshold energy (BTE), causes the binary breakup of the system. The grey scale demonstrates a weak mixing between the nucleons of the projectile and the target, proving a strong memory of the entrance channel and implies an important degree of nuclear matter transparency. Neither experimental quantitative probes nor careful theoretical studies have been performed on this subject so far. It should be underlined that the LV model calculation is a quasideterministic one without genuine quantal fluctuations. Thus, the model is able to provide only an average value for the BTE.

The results of the recent INDRA experiment on the Ar+KCl reaction [6,7] qualitatively endorse the LV model predictions. The most relevant result to the present study is the behavior of the correlation yield of the largest ($Z_{\rm max}$) and the second largest ($Z_{\rm max-1}$) fragment measured at 32 MeV/nucleon. After selecting the most central events ($<0.04\times\sigma_{\rm reac}$), the fusion-like events (the large values of $Z_{\rm max}$ and the small values of $Z_{\rm max-1}$) account for 43 mb only. All other events contribute to the BM (two main fragments of approximately the same charge, $Z_{\rm max} \approx Z_{\rm max-1}$) representing a half of events in this subset (44 mb) [7] (see also in [8]).

It has to be stressed at this point that the LV equation solved for the local Skyrme III interaction fails to describe the Ar+KCl data. Indeed, with the stiff EOS (K_{∞}=380 MeV), the binary channel never opens (between 65 and 70 MeV/nucleon the multifragment production replaces fusion), whereas with the soft EOS (K_{∞}=200 MeV), the binary channel opens but, the threshold energy is as high as 42 MeV/nucleon.

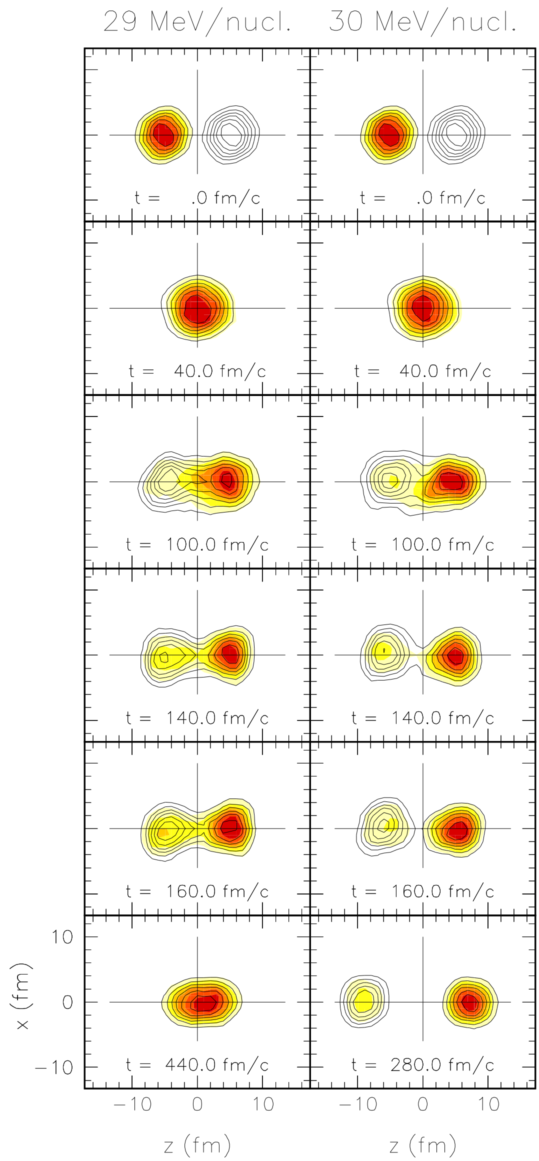

Fig. 1. Equidistant density-profile contours in the configuration space at several times of the reaction projected onto the reaction plane for Ar+Ar head-on collisions at 29 MeV/nucleon (left column) and at 30 MeV/nucleon (right column). The curves refer to the whole system, whereas the scale of grey shows the projectile matter density. The z axis is along the projectile direction.

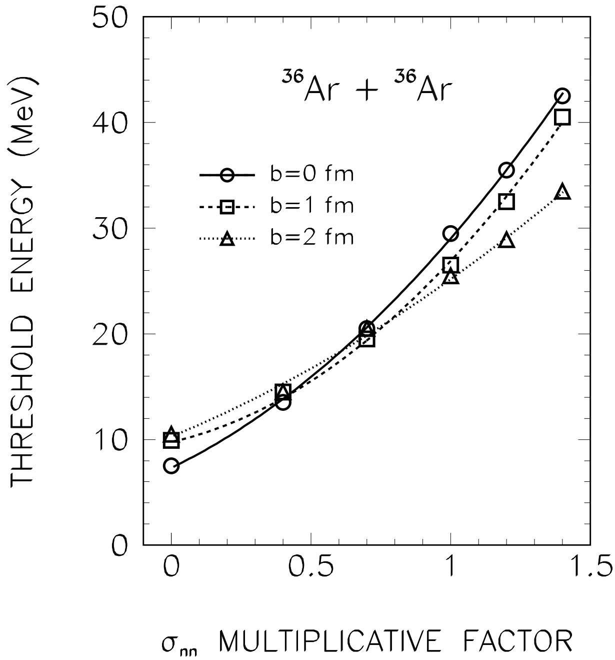

Fig. 2. The binary-reaction threshold energy for the Ar+Ar collision as a function of the NN cross section multiplicative factor for b=0 (circles and solid curve), b=1 (squares and dashed curve), and b=2 fm (triangles and dotted curve).

The stopping power of the collision, hence the transparency, depends crucially on the value of σ_{NN}. Besides the free NN cross section σ_{NN}^{f} with its usual energy and isospin dependence, the in-medium effects were studied for the impact parameters b=0, 1, and 2 fm by varying the σ_{NN} between 0 (pure one-body dissipation via the Vlasov equation) and $1.4\times\sigma_{NN}^{f}$. In each case, the BTE was searched for by scanning the incident energy in a step of 1 MeV/nucleon. The results are displayed in Fig. 2. One observes a regular dependence of the BTE on the value of σ_{NN}. This dependence is steepest for head-on collisions (solid curve), but the b=1 fm collision (dashed curve), which is accessible experimentally, shows the same behavior. Therefore, the onset of the binary reaction channel can be used to constrain the value of the in-medium σ_{NN}. A detailed study has been carried out for several light and moderately heavy systems [9] proving the universality of the observed features.

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