Entrance-channel potentials in the syntheses of the heaviest nuclei

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The mechanism of compound-nucleus formation by the fusion of very heavy nuclei is an outstanding problem in the synthesis of super-heavy elements (SHEs) [1, 2]. The ultimate aim is the description of fusion as part of the quantum-mechanical scattering process between two nuclei. In such a formulation one has to consider all kinds of channels which are coupled (in general non-perturbatively) to the entrance channel of the colliding nuclei. Thus one faces the problem of describing the coupling of a large number of channels, which include inelastic excitations and transfer, quasi-fission, fusion and compound-nucleus formation. One of the crucial steps in such a description is the coupling of the entrance-channel wave function to more compact configurations. It is obvious that the energy dependence of the entrance-channel wave-function strongly affects the cross-sections for all processes including those which involve compact-shape configurations. Therefore, we are interested to understand as a first step the basic properties of the entrance channel in fusion reactions.

Since the approach of the colliding nuclei is fast compared to the relaxation process, the frozen-density approximation has been used for defining the entrance-channel potentials. Microscopic Hartree-Fock-Bogoliubov calculations are used to obtain these densities, while the Thomas-Fermi approximation, extended to include all terms up to second-order spatial derivatives [3], has been applied together with Skyrme energy densities to obtain the energy of the system as function of distance.

The results on cold-fusion systems (^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni,^{70}Zr,^{76}Ge, and ^{86}Kr on ^{208}Pb and oblate ^{198}Pt, as well as symmetric systems with $A_1 \approx A_2 \approx 120...150$) and hot-fusion systems (^{48}Ca and ^{40,42}Ca on ^{238}U, ^{244}Pu, ^{248}Cm, and ^{252}Cf, as well as ^{50}Ti, ^{54}Cr, ^{58}Fe, ^{58}Ni, ^{64}Ni, ^{68}Ni, ^{70}Zr,^{78}Ge, ^{74}Se, ^{82}Se on ^{238}U and ^{252}Cf) are reported and discussed in [4].

An example (^{70}Zr+^{208}Pb) is shown in Fig. 1. The main features of the entrance-channel potential are summarized as follows.

- The potential pocket are much shallower then for light systems (e.g. ^{58}Fe+^{64}Ni).
- The observed fusion windows (vertical thick bar in Fig. 1) lie systematically 5 to 10 MeV below our barriers, indicating the importance of subbarrier processes like transfer and collective deformations.
- With increasing masses of the projectile and target the pockets and energy difference between barrier and compound-nucleus g.s. energy decreases.

The barriers obtained with the help of different analytical expressions for nucleus-nucleus potentials introduced by Bass in 1974 [5] and in 1980 [6], by Blocki et al. (proximity 77) [7] and by Krappe-Nix-Sierk (KNS) [8] are spread over a very wide interval, as shown in Fig. 1b. The differences between the barriers evaluated in these approaches reach 25 MeV. The KNS potential is closest to our ETF potential. The results for the KNS potential is presented only up to the touching point.

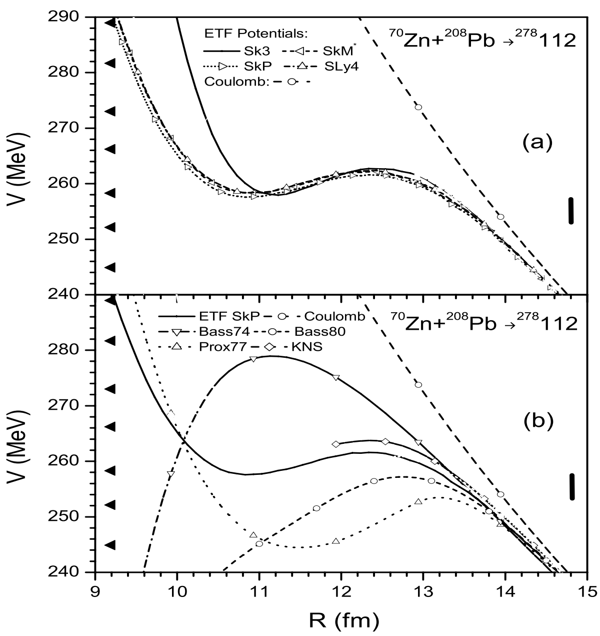

Figure 1: **(a)** The interactiion potentials for ^{70}Zr+^{208}Pb evaluated in the ETF approximation with the Skyrme forces SIII, SkM*, SkP and SLy4. For comparison also the Coulomb potential is given. The energy window for observed SHE formation range of collision energies for observed synthesis of the SHE 112 [1] is marked by vertical thick bar. The ground-state Q-value is indicated by the lowest triangle at the left vertical axis. The other 6 triangles mark, respectively, the thresholds for the emission of 1, 2, 3, 4, 5 and 6 neutrons. **(b)** The potentials for the collision system ^{70}Zr+^{208}Pb obtained in the ETF approximation with the Skyrme force SkP in relation to the proximity (1977), the Bass (1974, 1980) and the KNS potentials.

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