Mechanism of complete fusion by nucleon transfer in heavy ion collisions

List of co-authors:

A. Nasirov[1], G. Adamian[1], Sh. Kalandarov[1], G. Giardina[2], G. Mandaglio[2], B. Kayumov[3], O. Ganiev[3], G. Yuldasheva[3]

[1] Bogoliubov Laboratory of Theoretical Physics at JINR

[2] University of Messina (Italy)

[3] Institute of Nuclear Physics of the Uzbekistan Academy of Sciences

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The new mechanism of the incomplete fusion has been suggested and proved firstly in Ref. [1] by us against being used but not proved mechanism assuming breakup of the projectile before capture with the target nucleus. The dynamical method of the capture calculations allows us to determine the angular momentum distribution which determines the competition between complete fusion and quasifission, as well as the competition between fusion-fission and particle evaporation at the de-excitation of the compound nucleus. The reality of the new mechanism of the incomplete fusion has been proved as the emission of the α particle from the very mass-asymmetric state of the DNS due to the appearance of the intrinsic fusion barrier to complete fusion in collisions with the large orbital angular momentum ($L > 30\hbar$). This effect has been found by solution of the set of the master transport equations for the charge distribution as a function of the beam energy and angular momentum [1]. The centrifugal energy causing emission of the α particle leads to strong decrease the excitation energy of the conjugate nucleus. As a result the evaporation residue cross section of the de-excitation cascade increases becoming larger than the one of the de-excitation of compound nucleus formed in the complete fusion of colliding nuclei. This property of the incomplete fusion may be useful in synthesis of the super-heavy elements or new isotopes.

In paper [2], the firstly we have clarified reasons of the difference in the observed ER cross sections of the ^{34}S+^{208}Pb and ^{36}S+^{206}Pb reactions for the 2n and 3n channels. The first reason is that the capture cross section of the latter reaction is larger than the one of the ^{34}S+^{208}Pb reaction since the nucleus-nucleus potential is more attractive in the ^{36}S+^{206}Pb reaction due to two more neutrons in isotope ^{36}S. The second wanted reason is the difference in the heights of the intrinsic fusion barrier $B^{*}_{\rm fus}$ appearing on the fusion trajectory by nucleon transfer between nuclei of the DNS formed after the capture. It has been found by the analysis of the non-equilibrium the proton and neutron distributions between fragments of the DNS formed in the reactions with the ^{34}S and ^{36}S. We have found that the value of $B^{*}_{\rm fus}$ for the ^{34}S+^{208}Pb reaction is higher than the one obtained for the ^{36}S+^{206}Pb reaction. The experiments [J. Khuyagbaatar et al., Phys. Rev. C 91, 054608 (2015)] devoted to establish the second reason by the comparison of the fusion-fission yields in these reactions did not show any difference between their results.

Mass distribution studies play an important role in understanding the fusion-fission mechanism involved in the heavy-ion induced nuclear reaction [3]. An increase in the width of the mass distribution of the observed fusion-fission products in the mass asymmetric region is interpreted in terms of the mixing of fusion-fission and quasifission events. The quasifission contribution to the mass distribution of the fusion-fission products has been calculated due the request of the experimental groups from India. The contribution of the quasifission products to the yield of the binary fragments with the mass numbers around A = 80–110 and A = 170–200 is dominant in the ^{48}Ti +^{232}Th reaction [3]. The contribution of the symmetric quasi-fission products to the yield of the mass symmetric region is comparable with the yield of the fusion-fission products [3] while it is less for the quasi-fission products in the ^{48}Ti +^{208}Pb reaction [4]. The yields of products of multinucleon transfer reaction ^{48}Ca + ^{248}Cm at energies around the corresponding Coulomb barrier are rather well in agreement with the experimental cross sections of isotopes with $N > 126$ but deviates from the experimental cross sections for the very neutron-deficient Pa and U isotopes [5]. The production cross sections of neutron-deficient isotopes $^{108–110}$Xe, $^{112–114}$Ba [6], ^{200,204}Po, ^{184,190}Hg and ^{206,212}Rn, ^{216,220}Ra [7] have been compared with the available experimental data. The optimal beam energies and corresponding maximum production cross sections of new isotopes are predicted. Ref. [8] is devoted to prediction for the synthesis superheavy element with Z = 119 by the analysis of the complete fusion, quasifission, fast fission, and evaporation residues formation stadies of the ^{54}Cr + ^{243}Am reaction.

Conclusion is that complete fusion mechanism is one of channels of the multi-nucleon transfer reactions and compound nucleus is an extremal state of the DNS reached after transfer all nucleons from its light fragment to the heavy one.

List of publications:

1. A.K. Nasirov et al., Phys. Lett. B 842, 137976 (2023).
2. A.K. Nasirov et al., Eur.Phys.Jour. A55, 29 (2019).
3. Shruti et al., Eur. Phys. J. A 59, 238 (2023).
4. Meenu Thakur et al., Eur. Phys. Jour. A, 53, 133 (2017).
5. Sh. A. Kalandarov et al., Phys. Rev. C 102, 024612 (2020).
6. Sh. A. Kalandarov et al., Phys. Rev. C 93, 054607 (2016).
7. Sh. A. Kalandarov et al., Phys. Rev. C 108, 054612 (2023).
8. B. M. Kayumov et al., Phys. Rev. C 105, 014618 (2022).