Sub-barrier fusion of weakly bound nuclei: Strong enhancement due to sequential fusion mechanism

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The reactions with halo neutron-rich nuclei during the past 10 years has been of increased interest from experimental and theoretical point of view. In particular, much effort has been devoted to studying near-barrier fusion of light weakly bound nuclei. Unusual effects are expected here both from the halo structure of these nuclei and from specific tunnelling mechanism of the composed weekly bound system which is also of common interest for quantum theory.

Neutron transfer cross sections are known to be rather large at near-barrier energies of heavy-ion collisions and there is a prevailing view that coupling with the transfer channels should play an important role in sub-barrier fusion of heavy nuclei. For weakly bound nuclei (the two-neutron separation energy for ^{6}He is less than 1 MeV) a strong coupling with the break-up channels is also evident and it should influence significantly the fusion probability. However, while the role of collective degrees of freedom (rotation of statically deformed nuclei and/or vibration of nuclear surfaces) in the sub-barrier fusion reactions is well studied in many experiments and well understood theoretically, the role of neutron transfer and break-up channels is not so clear.

A series of experiments was already undertaken on the near-barrier fusion of ^{6}He with ^{209}Bi [1, 2] and ^{238}U [3, 4]. However, the contradictory conclusions were made concerning a role of weakly bound neutrons in the fusion process and, no matter how surprising it may seem, but until now there is no consensus (neither in theory nor in experiment) on the extent to which the sub-barrier fusion of weakly bound nuclei differs from fusion of ordinary ones.

Recently in Ref. [5] a new mechanism has been assumed for the sub-barrier fusion of weakly bound nuclei, in which an intermediate rearrangement of valence neutrons with positive Q values may lead to a gain in kinetic energy of the colliding nuclei and, thus, to enhancement of the barrier penetrability. Within this "sequential fusion" mechanism, the fusion enhancement in the reactions ^{40}Ca+^{48}Ca (compared with ^{48}Ca+^{48}Ca), ^{40}Ca+^{96}Zr (compared with ^{40}Ca+^{90}Zr) and ^{18}O+^{58}Ni (compared with ^{16}O+^{60}Ni) has been successfully explained. A new experiment was proposed in Ref. [5] for measuring and comparing the evaporation residue cross sections in the ^{6}He+^{206}Pb and ^{4}He+^{208}Pb reactions leading to the *same* compound nucleus. The yield of polonium isotopes at the same sub-barrier center-of-mass energy of 15 MeV (5 MeV below the barrier) was predicted to be *three orders* of magnitude larger for the first reaction as compared to the second one. This experiment has been performed recently in Dubna [6], and preliminary analysis of the data obtained confirms the predictions.

The subject will be discussed in the talk along with detailed analysis of the "sequential fusion" mechanism performed within the time-dependent Schrödinger equations. An importance of the effect for synthesis of new superheavy nuclei in future experiments with accelerated neutron-rich fission fragments as well as for astrophysical estimations will be also discussed in the talk.

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