Langevin Approach to Nuclear Dynamics and Fusion Hindrance of Massive Nuclear Systems

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Synthesis of superheavy elements becomes more and more difficult experimentally as an atomic number of the element becomes larger. The residue cross sections become smaller and smaller, and now less than 1.0 pb. Therefore, a reliable theoretical prediction is strongly desired. The smallness of the cross sections stems from the two factors ; the fusion and the survival probabilities. The latter should be extremely small because the fissility parameters are close to 1, and thus there is no macroscopic fission barrier which sustains the nuclei against fission, that is, only the shell correction energy can give rise to their stability. In brief, the superheavy nuclei are inherently fragile. The fusion probability has been experimentally known to be very small in massive systems. The fusion is even hindered, which is shown typically by the necessity of so-called "extra-push energy". Theoretically, its physical mechanism has not been well understood, but is elucidated recently. Even, analytic formulae for the hindered probability as well as for the extra energy are given. [1]

In practice, fusion probabilities are obtained by solving a Langevin equation numerically with realistic parameters for the potential, the inertia mass, friction tensor, etc. There, at least three degrees of freedom have to be solved, say, distance(radial) beteween two mass-centers, mass-asymmetry and neck between two mass centers. Numerical calculations of three-dimensional Langevin as well as analyses of their results are quite complicated and thus, might include errors. In order to avoid them and/or to confirm their validity, it is necessary to employ analytic solutions of the problem with simplifications of the physical parameters. Comparisons of the numerical results with the analytic ones are very helpful for that. With Laplace transformation, we can obtain a simple analytic expression for a parabolic potential. The method can be extended to Non-markovian cases. [2] It is also shown that the method gives the essentially the same simple expression to various generalized memory kernels such as that from the quantum heat bath. [3] This developments are very important and useful for nuclear dynamics. As is welknown, in nuclear physics case collective motions are supposed not to be ideal Brownian one, where the time scales of collective variables are not well separated from that of the heat bath and thus, the memory kernel for friction is accompanied.

Another way to reduce heavy numerical tasks is to inspect time scales of the collective motions. Actually, The motion related the neck-filling in di-nucleus configuration which is the starting one in the fusion process is found to be far quick , compared with that of radial motion, i.e., that of diffusion of the distance variable. This permits us to first solve the neck-filling, and then solve the remaining two degrees. [4]

For predictions of the residue cross sections, we have to upgrade the reliability of calculations of the survival probability. For that, we have developed a new computer code for the statistical decay KEWPIE II. With this work, one of the collaborators, Anthony Marchix has obtained Ph D at Univ. of Caen, Nov. 2007.

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