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Uncertainties and understanding of experimental and theoretical results regarding reactions forming heavy and superheavy nuclei

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Abstract

Experimental and theoretical results of the P_{CN} fusion probability of reactants in the entrance channel and the W_{sur} survival probability against fission at deexcitation of the compound nucleus formed in heavy-ion collisions are discussed. The theoretical results for a set of nuclear reactions leading to formation of compound nuclei (CNs) with the charge number $Z = 102$–122 reveal a strong sensitivity of P_{CN} to the characteristics of colliding nuclei in the entrance channel, dynamics of the reaction mechanism, and excitation energy of the system. We discuss the validity of assumptions and procedures for analysis of experimental data, and also the limits of validity of theoretical results obtained by the use of phenomenological models. The comparison of results obtained in many investigated reactions reveals serious limits of validity of the data analysis and calculation procedures.

Keywords: Nuclear reactions; Fusion probability; Surviving probability of CN; Heavy and superheavy elements

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1. Introduction

The study of the nuclear reactions in heavy ion collisions continues to excite great interest in the scientific community to better understanding the reaction dynamics from the stage of capture of the projectile by target-nucleus up to the formation of the reaction products. The knowledge about reaction dynamics is important in planning possible experiments suitable to form heavy and superheavy compound nuclei leading to evaporation residues (ERs) and identifiable fragments belonging to the fusion–fission process. It is clear that the differences between the experimental results measured for the same quantities in the same nuclear reactions are explained by the specific conditions present in the overall experimental apparatus and data analysis. The differences between the theoretical results calculated by the different models are related to the assumptions made in the procedures of theoretical calculations and use of simplified phenomenological models unsuitable to describe the reaction dynamics. In fact, in this last case the use of free parameters can lead to an apparent acceptable agreement between the calculated results and data but actually these results can not prove the effectiveness of the procedures used to obtain the experimental results. Analogously, the procedure of obtaining the best values of free parameters used in the phenomenological model which leads to results of calculation in good agreement with the obtained experimental results can not demonstrate by a clear and unambiguous way the understanding of the reaction dynamics, from the stage of colliding nuclei up to the achievement of the final products.

The reliability of the experimental results can be improved by decreasing the number of assumptions due to the increase of the measured physical quantities and their correlation.

The evaporation residues (ERs) are registered enough unambiguously since those products can be separated easily from the ones of the other events. Therefore, theoretical results are aimed to be close to the experimental data of evaporation residues. Furthermore, there are difficulties in estimating the incomplete fusion contribution [1–3] in the formation of the evaporation residues since the ambiguities of its mechanism are appeared.

The main reason for the differences in the experimental fusion and capture cross sections is related to the ambiguity of the procedures at the separation of the events corresponding to deep-inelastic collisions (DICs), quasifission (QF) and fusion–fission (FIS) processes. The quasifission is the decay of the DNS into two fragments without formation of CN. There is still no definite understanding nature of full momentum transfer reactions in the experimental analysis of the deep-inelastic collisions and quasifission events to estimate capture cross sections. The overlap of the mass and/or angular distributions of the quasifission and fusion–fission products causes ambiguity in the estimation of the experimental fusion cross sections.

The choice of degrees of freedom and interaction forces involved in calculations are directed to simplify the complicated or unknown nature of the physical processes of the heavy ion collisions. Therefore, the deviations between the experimental results and the various theoretical ones are inevitable.

The P_{CN} fusion probability of reactants in the heavy ion collisions is estimated as a ratio of the complete fusion (σ_{fus}) and capture (σ_{cap}) cross sections:

$$P_{CN} = \frac{\sigma_{fus}}{\sigma_{cap}} = \frac{\sigma_{fus}}{\sigma_{fus} + \sigma_{qfis}}. \quad (1)$$

The capture cross section is determined by the estimation of the range of the orbital angular momentum leading to the full momentum transfer in the entrance channel of collision. The evolution of the excited dinuclear system (DNS) formation can lead to complete fusion in competition