Entrance channel effect in characteristics of the heavy ion reaction products

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Introduction

The mechanism of heavy ion collisions can be studied by analysing energy, mass and angular distributions of the products observed in various reaction channels. The correlations between these distributions then allow us to extract the information about the formation and decay of a metastable composite system, if any, such as a dinuclear system (DNS), during the contact time of interacting nuclei [1, 2]. When the yield of evaporation residues is not main contribution in reaction products, an ambiguous estimation of the complete fusion cross section appears due to overlaps of the mass and angular distributions of the products formed in the fusion-fission, fast fission, deep-inelastic collision and quasifission products.

Experimental and theoretical uncertainties in estimation of the fusion probability

The reasons leading to uncertainties of the experimental and theoretical values of the fusion probability $P_{\rm CN}$ in heavy ion collision at lower energies are discussed. The P_{CN} fusion probability of reactants in the heavy ion collisions is estimated as a ratio between the complete fusion ($\sigma_{\rm fus}$) and capture ($\sigma_{\rm cap}$) cross sections:

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

It should be stressed that there are two important reasons causing the uncertainties of the experimental values $P_{\rm CN}$. The first reason is related to the ambiguity in identification of the reaction products formed by the true capture and fusion events. In the analysis of experimental data with full momentum transfer, events with masses around the values of the projectile nucleus and conjugate nucleus are not usually taken into consideration. Those events are considered as originated by the deep-inelastic collisions and this procedure of the analysis leads to a decrease of the experimental value of the capture cross section $\sigma_{\rm cap}^{(exp)}$ and, consequently, to increase fusion probability $P_{\rm CN}$ since it inverse proportional to $\sigma_{\rm cap}^{(exp)}$. For example, the authors of ref. [3] considered the reaction products with mass numbers $A < 60$ as the ones of the deep-inelastic collisions and the capture events (characterized by the large energy dissipation and with a full momentum transfer) are missed. Therefore, the restriction of the mass range $60 \leq A \leq 130$ for the capture products is not completely correct because this assumption in the procedure of analysis of selection of experimental capture events leads to decrease the estimated true experimental capture cross sections. Therefore, the $P_{\rm CN}$ fusion probability determined by the analysis of experimental events as the ratio between the fusion and capture cross sections is larger than the true experimental value.

The second reason is the ambiguity in the separation of the fusion-fission events in the analysis of fission-like products contain-

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ing quasifission or/and fast fission products. Therefore, the number of events seem to be larger than true fusion events due to consideration of the part of quasifission and fast fission events as fission events of compound nucleus which has not formed in the reaction. Certainly the extracted fusion probability P_{CN} will be larger than its correct value.

The Australian group have obtained interesting results about angular and mass distributions of fissionlike products [4, 5]. The relation between characteristics of the measured angular and mass distributions and the entrance channel properties will be discussed.

The effect of quasifission on the evaporation residues cross section

The hindrance to complete fusion is mainly caused by the quasifission process. The yield of the evaporation residues proves surely that the complete fusion has taken place. A comparison of the experimental cross sections of the evaporation residues in reactions leading to formation of the less fissible compound nucleus is a good way to estimate the contribution of the quasifission in the reaction mechanism in reactions with heavy ions at low energies. The recent work [6] of the Indian experimentalists is a reliable demonstration of the strong role of the quasifission as a hindrance to complete fusion. The theoretical analysis of the entrance channel effect has been done in our recent work in cooperation with the colleagues from Republic of Korea [7].

It is seen from comparison of the evaporation residue cross sections. In case of the very asymmetric reactions, the mass and angle distributions of the fission-like products are less sensitive than evaporation residue cross sections since an overlap of the mass distributions of the quasifission and fusion-fission products are not strong. In case of the very asymmetric reactions, the quasifission products contribute only to the asymmetric part of the mass distribution of the fusion-fission products causing increase of its widths. The mass distribution of the reaction products is sensitive of the shell structure of the projectile and target nuclei, as well as to the shell structure of the being

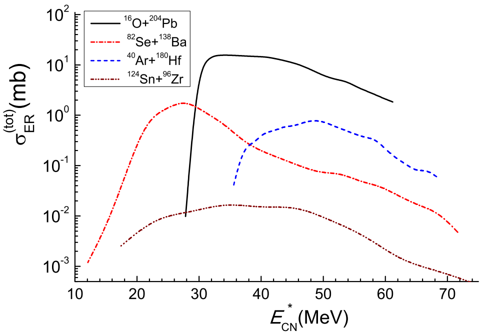

FIG. 1: Comparison of the total cross section of the evaporation residues in reactions leading to ^{220}Th.

formed reaction products.

Therefore, it is important to study the dependence of the reaction mechanism on the entrance channel properties which can be either controlled or either not. The orbital angular momentum of colliding nuclei and the orientation angles of their axial symmetry (if one or both of them are deformed) are out of the control of experimentalists.

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