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Reaction mechanism studies using the CN/ER spin distribution

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Abstract. To study basic properties of the fusion reaction dynamics for heavy compound systems the partial-wave distribution σ_ℓ can be employed as an alternative to the classically used fusion/fission excitation functions. A variety of reactions leading to compound nuclei (CN) in the Pb region can be used to investigate features like the fusion-fission competition, the role of deformation in the fusion of heavy systems and a possible effect of the $Z = 82$ shell on the enhancement of evaporation residue (ER) production.

PACS. 24.75.+i General properties of fission – 25.70.Gh Compound nucleus – 25.70.Jj Fusion and fusion-fission reactions

1 Introduction

The assumption that shell effects in the CN could favor the production of ER was not confirmed for the $N = 126$ shell [1]. Nevertheless, recent results from Dubna, where various α-decay chains for ^{48}Ca on ^{244}Pu and ^{248}Cm were interpreted as 3n or 4n reaction channels leading to isotopes of elements 114 [2] and 116 [3], make it possible to discuss that shell stabilization close to the next higher proton shell could favor the synthesis of heavy nuclei. The peculiarity here is a more or less constant cross-section in the pbarn range which breaks the trend of steep decrease with Z observed for all other reactions leading to ER with $Z \geq 102$. In a simple picture a deeper potential due to a shell energy E_{shell} shifts the critical angular momentum ℓ_{crit} to higher spins as shown in fig. 1. The deformation of one reaction partner could enhance this effect due to the increased moment of inertia in the entrance channel. ^{244}Pu and ^{248}Cm are well-deformed nuclei and the isotopes which have been interpreted as ER are close to a region where, according to theoretical expectations (see, *e.g.*, [4]), shell stabilization sets in.

2 Nuclear-structure effects

The importance of the nuclear structure of target and projectile for the fusion reaction cross-section has been extensively studied throughout the last two decades in various laboratories [5–7]. The effect of low-lying excitation levels as well as of deformation could be shown, in particular, by precisely measured fusion excitation functions. This provides an experimental access to the fusion barrier distribution [5]. Particularly clear signatures are produced by deformed reaction partners. This had been observed in some cases as a different slope of the fusion excitation function already in the late seventies for reactions with ^{16}O on various Sm isotopes [8]. It has also been suggested that the

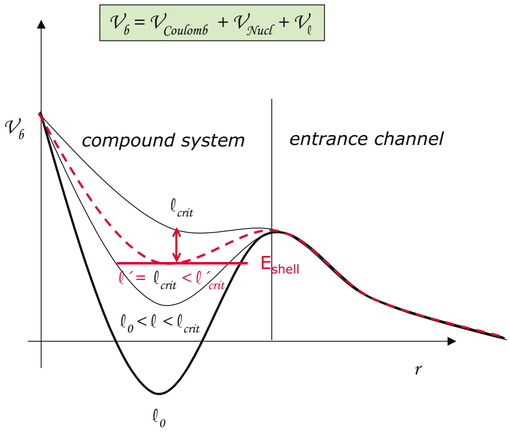

Fig. 1. Schematic illustration of the variation of the fusion potential with ℓ and the effect of E_{shell}.

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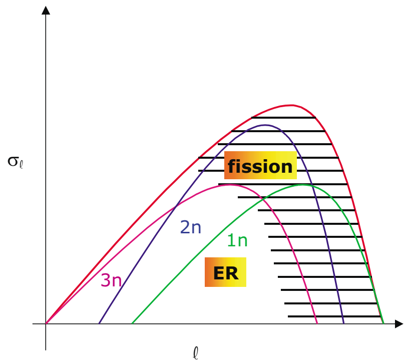

Fig. 2. Qualitative picture of the partial-wave distribution with the distribution of ER as a function of spin and the effect of fission at high angular momenta

deformation in the entrance channel could favor the fusion of very heavy systems due to their ability to form a more compact configuration [9]. The influence of these structure effects in heavy-ion fusion processes has been extensively studied via the extraction of an experimental representation of the barrier distribution (ERBD) governing fusion [10,11]. In a recent experiment, C.R. Morton and co-workers could investigate the effect of nuclear deformation in terms of the ERBD [12] for ^{34}S + ^{168}Er. It has the expected shape for the large quadrupole deformation of ^{168}Er. The precise fission and ER excitation function obtained there makes this reaction an ideal starting point for our investigations (see final section).

3 Spin distribution (SD)

As mentioned above, the second derivative of the function $E\cdot\sigma_{\rm fus}$ (barrier distribution) has proven to be a useful tool to investigate the reaction dynamics [5]. One can show that the same information can be obtained from the CN spin distribution [13]. At each energy, in fact, it contains information on the single partial-wave cross-section which is otherwise hidden in the integral $\sigma_{\rm fus}$. Starting from the partial-wave ansatz the equivalence

$$D_{\rm B} = \frac{1}{\pi R^2}\frac{{\rm d}^2\sigma_{\rm fus}E}{{\rm d}E^2} = \frac{{\rm d}T_{E'}}{{\rm d}E'}. \qquad (1)$$

can be derived [15]. For increasing mass of the compound system, fission comes into play as a relevant reaction channel. In particular, for the production of the heaviest elements, the competition between fission and particle evaporation becomes decisive for the survival of the ERs. To understand the 2-step process of fusion and de-excitation, the necessity arises to have a comprehensive description of both the entrance channel properties of the system as well as the role of the fission barrier in the exit channel. The effect of fission on the SD has been qualitatively shown in ref. [14] for the system ^{64}Ni + ^{100} Mo using the Argonne/Notre Dame BGO array. A clear change of the slope at high angular momenta has been observed at energies where fission becomes the main reaction channel. In fig. 2 a schematic picture of the CN spin distribution is drawn showing the distribution of ER channels and the effect of fission. The SD itself can be extracted from measured γ-multiplicities M_γ with a multiplicity filter [15] like the inner ball of GASP. In the context of fission competing with particle evaporation it is very interesting to investigate which partial waves are contributing to the ER production. At high ℓ a substantial part of the excitation energy can be stored in the rotation. For nuclei which are stabilized only by their shell structure, shell correction energies of the order of a few MeV could lead to higher survival probabilities. The investigation of ER spin distributions would reveal such an effect if present.

4 Status of the experiments

All three aspects, investigation of the $Z = 82$ shell, the role of deformed reaction partners and fusion-fission reaction dynamics, can be combined by choosing suitable projectile-target combinations. We started a series of experiments studying the SD in the vicinity of $Z = 82$ as well as fusion/fission excitation functions. A first run has been performed by Sagaidak *et al.* [16] for the measurement of ER and fission excitation function for ^{48}Ca + ^{168,170}Er at the LNL. The residues of these reactions cross as a function of the kinetic energy, that determines the number of evaporated neutrons, the $N = 126$ shell at ^{214}Ra. To study the SD we measured γ-multiplicities with GASP in a first experiment for the reactions ^{64}Ni + ^{100}Mo and ^{34}S + ^{168,170}Er. First preliminary results of these reactions indicate the feasibility of the method and the consistency with earlier results [14]. SD-measurements for ^{48}Ca + ^{144,154}Sm have been started in October 2002. Fusion-fission data for ^{48}Ca + ^{154}Sm has been taken in spring 2002. This subset of reactions covers already the aspects of deformation and the role of the $Z = 82$ shell.

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