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N/Z INFLUENCE ON DISINTEGRATION MODES OF COMPOUND NUCLEI*

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Investigations on the influence of the neutron enrichment on the decay channels of excited nuclei are presented. Characteristics of fragments with charge $6 \leq Z \leq 28$ emitted in ^{78,82}Kr+^{40}Ca at 5.5 MeV/A reactions were measured at the GANIL facility. Data are compatible with an emission process from compound nucleus and are discussed in the framework of the transition state model.

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1. Introduction

Nuclei produced under extreme conditions drives a major part of experimental and theoretical investigations. Fusion process at incident energy around the Coulomb barrier is well adapted to form hot and rotating compound nuclei in a controlled way. These excited nuclei decay via a variety

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of channels, from light particles emission to fission mechanism. Study of the disintegration modes allows to extract quantities as level density parameters, fission barriers or nuclear viscosity. The neutron-to-proton ratio (N/Z) of the compound nuclei is expected also to play a crucial role in the competition between disintegration modes and in the nuclear quantities quoted above. In this contribution we present data on the production of fragments with charge $6 \leq Z \leq 28$ emitted in ^{78,82}Kr+^{40}Ca fusion reactions at 5.5 MeV/A incident energy.

2. Experimental results

The experiments were performed at the GANIL facility. Beams of ^{78,82}Kr were used to bombard a self-supported ^{40}Ca target of 1 mg/cm^2 in thickness.The kinetic energy of the ejectiles was measured with the 4π-INDRA array [1]. For $3^\circ \leq \theta_{\rm lab} \leq 45^\circ$, each detection ensemble is made of ionization chamber, silicon detector and CsI. The energy calibration was deduced from the Kr + Ca elastic scattering.

The angular dependence of the centre-of-mass average velocity of fragments with atomic charge $Z = 10, 15, 20, 25$ and the angular distributions for same fragments are shown in Fig. 1 (left panel) for the ^{78}Kr+^{40}Ca reaction. Results obtained in the ^{82}Kr+^{40}Ca reaction are similar. For fragments with atomic charge $6 \leq Z \leq 28$, the range $3^\circ \leq \theta_{\rm lab} \leq 45^\circ$ covers the forward hemisphere in the centre-of-mass frame of the reaction. The centre-of-mass average velocity of fragments $V_{\rm cm}$ is roughly constant as a function of the emission angle. Moreover, $V_{\rm cm}$ agrees rather well with the predictions deduced from the Viola systematics [2] (horizontal lines on left pannel of Fig. 1). These features suggest a strong degree of relaxation in the mechanism leading to the formation of the observed fragment and an emission governed mainly by Coulomb interaction. The angular distribution $d\sigma/d\theta_{\rm cm}$ are rather flat. All these characteristics are consistent with an emission from a compound nucleus. The absolute cross-sections were obtained from the normalization to the elastic scattering measured at a laboratory angle for which the cross-section is given by the Rutherford formula.

The cross-section distributions (not shown here) for ^{78,82}Kr+^{40}Ca systems reach a maximum for a fragment with Z around half of the charge of the compound nuclei. This indicates that elements around symmetry come from a fission process at high angular momentum. The yields for symmetric splitting is larger for the ^{78}Kr+^{40}Ca system. A probable explanation would be that the fission barrier for the neutron poor system is smaller than for the neutron rich one. Since the cross-section depends on the thermal energy left, once the collective energy is subtracted a higher cross-section is expected for symmetric fission of ^{118}Ba compound nucleus. For light frag-

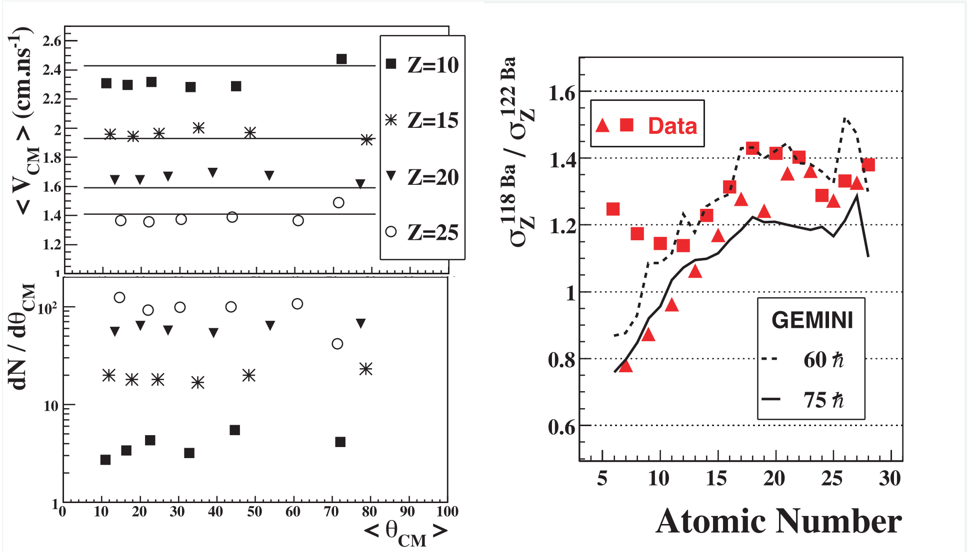

Fig. 1. Left panel: Experimental average velocity for fragments emitted in ^{78}Kr+^{40}Ca as a function of the emission angle in the centre of mass (top) and angular distribution in the centre of mass (bottom). Right panel: Experimental ratio $\sigma_Z^{118\text{Ba}}/\sigma_Z^{122\text{Ba}}$ (triangles and squares stand for odd-Z and even-Z fragments, respectively) compared to the GEMINI calculations for $J_{\max} = 60\hbar$ (dashed line) and $J_{\max} = 75\hbar$ (full line).

ments ($Z \leq 10$) a strong even–odd staggering is observed for both systems. The cross-sections for odd-Z fragments is higher for the neutron rich nuclei system while the cross-sections for even-Z fragments is higher for the neutron poor nuclei system. In the right panel of Fig. 1, the charge dependence of the ratio $R = \sigma_Z^{118\text{Ba}}/\sigma_Z^{122\text{Ba}}$ is presented. Even (odd) Z fragments are indicated by squares (triangles) symbol, respectively. The ratio R decreases roughly from 1.25 for $Z = 6$ down to 0.75 for $Z = 7$. For the odd-Z fragments, the ratio increases up to $Z = 21$ and reaches a kind of plateau. For the even-Z fragments, R decreases from $Z = 6$ to $Z = 10$ and then increases to reach the same kind of plateau as for odd-Z fragments. Since the excitation energy and the maximum angular momentum stored in compound nuclei are expected to be very similar in both reactions, the observed effects are probably due to the difference in the neutron enrichment of the compound nucleus. To summarize, one observes the coexistence of a gross feature that reasonably reflects the influence of the angular momentum and, on top of it, a staggering behaviour which demonstrates the persistence of structure effects in the process or the influence of the secondary decays. These various aspects will be discussed in the next section in the framework of statistical approach.

3. Comparisons with statistical calculations

Statistical decay calculations were performed using the GEMINI [3] code. All decay channels are calculated within the Hauser–Feshbach (for $Z \leq 2$) and transition state (for $Z \geq 3$) approaches. The key ingredient is the conditional saddle configuration which is constrained by the mass asymmetry. The saddle conditional energy for different mass (or charge) asymmetry was deduced from the Sierk's model [4]. In the present work, the fusion evaporation cross section is not yet available. For both studied reactions, the fission cross section is sensitive to the highest angular momentum leading to fusion mechanism. Thus, the maximum angular momentum $J_{\max}$ which reproduces the yields around the symmetric splitting could be considered as a good estimation of the $J_{\max}$ for fusion. Calculations have been performed using the standard parameters of the GEMINI code. The shape of the charge distribution around the symmetric fission could be satisfactory reproduced by varying $J_{\max}$ and the level density parameter values in a reasonable range for these reactions at low excitation energies ($J_{\max}$ between 60 and $75\hbar$ and a level density parameter value between $a = A/8$ and $a = A/9$). However, the relative yields between the light fragments and the symmetric fission is overestimated by the model. This disagreement would indicate a failure of the Sierk barriers and/or the transition state picture for large asymmetry and large angular momentum. The values predicted for the ratio $\sigma_Z^{118\mathrm{Ba}}/\sigma_Z^{122\mathrm{Ba}}$ are shown on the right panel of Fig. 1 for two values of $J_{\max}$. The model reproduces qualitatively the experimental data for light fragments with odd-Z and for $Z \geq 14$ but strongly underestimates the yields of even-Z fragments. The persistence of staggering effect indicates that the light fragments are emitted being relatively cold or emitted at a later stage of the separation process. Further investigations will be performed to extract the light charged particles emitted in coincidence with fragments. This will provide information on the particles produced before and after the fission process. Refinements are needed in statistical approach to describe the emission mechanism in an excitation range where structure effects influence strongly the phase space available for the disintegration.

REFERENCES

[1] J. Pouthas *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A357**, 418 (1995).

[2] C. Beck *et al.*, *Phys. Rev.* **C53**, 1989 (1996).

[3] R.J. Charity *et al.*, *Nucl. Phys.* **A483**, 43 (1988).

[4] A.J. Sierk, *Phys. Rev.* **C33**, 2039 (1986).