Complex nuclear-structure phenomena revealed from the nuclide production in fragmentation reactions

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Nuclear structure manifests itself in many features, which are widely investigated, e.g. in ground-state properties like binding energy, half-life, radius and deformation. Signatures of nuclear structure arise also in the production yields in specific nuclear reactions at low energies, gradually disappearing and transforming into smooth distributions with increasing excitation energy induced in the reaction. In the latest years signatures of nuclear structures were found in the production yields in deep-inelastic and in fragmentation reactions [1, 2, 3, 4, 5, 6, 7, 8], which can be quite violent and which are expected to introduce a large range of excitation energies in the nucleus.

Here we will report on the production yields from the projectile fragmentation of 1 *A* GeV ^{238}U nuclei in a titanium target, measured at GSI. The residual nuclei were fully identified in mass and atomic number with a high-resolution magnetic spectrometer, the FRS, and their production cross section were deduced. Details of the experimental set-up and of the analysis method can be found in ref. [9]. The data were filtered according to the *N-Z* number. The production cross sections of the observed fragments, grouped according to this filter, are shown in Figure 1. The data reveal a complex structure. All even-mass nuclei present a visible even-odd effect, which seems particularly strong for *N*=*Z* nuclei. Odd-mass nuclei show a "reversed" even-odd effect, with enhanced production of odd-*Z* nuclei. This enhancement is stronger for nuclei with larger values *N-Z*. However, for nuclei with *N-Z*=1 the reversed even-odd effect vanished out at about *Z*=16, and again an enhanced production of even-*Z* nuclei can be observed.

We tested the hypothesis that these fluctuations are produced at the end of the evaporation cascade due to the influence of nuclear structure on the properties of excited levels. Applying a statistical model, where pairing, modeled as a blocking effect, was introduced both in the masses and in the level densities, the number of bound states, representing the number of possible final states, was determined. For the odd-mass nuclei the statistical model reproduced the observed structural effects in all their complexity. For the even-mass nuclei, the statistical model predicted no structure at all. Analysing the experimental masses and energy levels found in literature, two important aspects emerged: 1) compared to other even-even nuclei, the *N*=*Z* nuclei, which are multiples of alpha particles, are exceptionally strongly bound, 2) while blocking effects are expected to destroy the even-odd staggering of the ground-state energies immediately, part of the even-odd staggering survives up to excitation energies in the order of 10 MeV above the ground state.

These findings go beyond the blocking effect of pairing and indicate more complex structural phenomena. Recently, possible origins for these structural effects, like mean-field contributions to pairing effects, alpha clustering and neutron-proton pairing, were discussed intensively [10, 11, 12].

Our experimental data suggest that structural effects are restored in the end-products of hot decaying nuclei, whose structure is ruled by the available phase space in the last step. It seems that a systematic investigation of the fine structure in the production yields from highly excited nuclei is a rich source of information on nuclear-structure phenomena in slightly excited nuclei found at the end of their evaporation process. It is a challenge to quantitatively interpret these results with theoretical models in order to better understand the complex nuclear-structure phenomena behind.

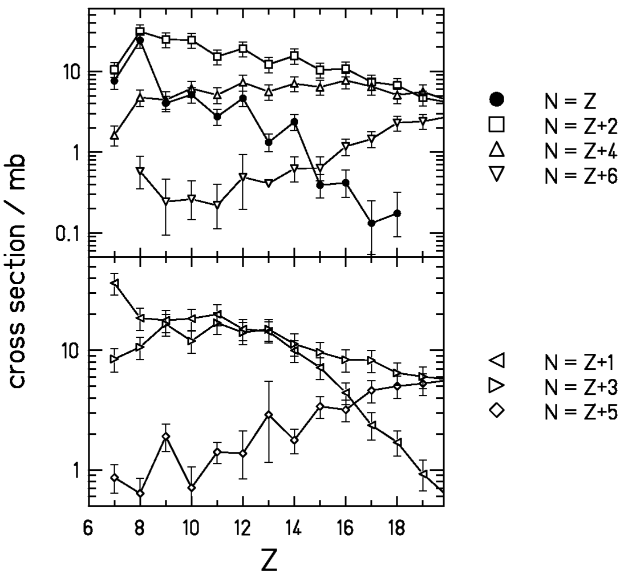

Figure 1: Formation cross sections of the projectile-like products from the reaction ^{238}U + Ti, 1 *A* GeV. The data are given along specific values of *N-Z*. The cross section for ^{32}Al (*Z*=13, *N*=*Z*+6) is an extrapolated value. The chain *N*=*Z* shows the strongest even-odd effect, while the chain *N*-*Z*=5 show the strongest "reversed" even-odd effect.

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