Research Group for Heavy Element Nuclear Science

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Studies of the chemical properties of the heaviest elements, and determination of the limits of nuclear stability, are among the most interesting, but also most challenging, topics in modern chemistry and nuclear physics. The research conducted by our group strongly focussed toward addressing these fundamental questions.

In nuclear physics, our core program is on fission, which is a unique physical process observed only in nuclear matter, and which provides the basis for numerous atomic energy applications. Our experimental and theoretical programs include also nuclear structure and reaction studies of exotic neutron- and proton-rich nuclei, as well as super-heavy nuclei. For nuclear chemistry, our work is concentrated on the heaviest elements, whose chemical properties are crucially determined by relativistic effects. Atomic and chemical properties of exotic atoms and molecules are studied via an atom-at-a-time chemistry approach.

Role of multi-chance fission in the description of fission-fragment mass distributions

For further public acceptance of nuclear power, it is essential to reduce the already-existing and newly produced nuclear waste. The use of accelerator-driven systems (ADS) is considered as one of the viable options for the incineration and/or transmutation of the long-lived minor actinides into shorter-lived fission products. In the ADS approach, energetic spallation neutrons could be used to irradiate the fissionable minor actinides. This leads to fission with higher excitation energies than the traditional light water reactors. In high-energy fission the so-called "multi-chance fission", i.e. fission after neutron-evaporation from compound nucleus, plays a role. We have investigated the effects of multi-chance fission on fission-fragment mass-distributions (FFMDs) in detail, from the measurement of FFMDs for twelve nuclides by multinucleon transfer channels in the reaction ^{18}O +^{238}U at the JAEA tandem facility [1]. It was found that the mass distributions for all the studied nuclides maintain a double-humped shape up to the highest measured energy in contrast to expectations of predominantly symmetric fission due to the washing out of nuclear shell effects, see Fig.1. From a comparison with the dynamical calculation based on the fluctuation-dissipation model (Langevin equations), it was found that the mass-asymmetric FFMDs observed at the high-energy region are caused by the fissions of lower-excited lighter isotopes generated by higher-order neutron-evaporation steps.

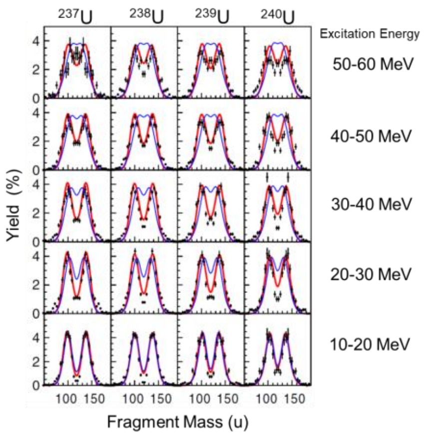

Fig.1 Fission-fragment mass distributions of uranium isotopes. The red and blue curves are the results of Langevin calculation with and without taking into account the multi-chance fission.

Systematic shell-model calculations of β-decay properties in neutron-rich nuclei

β-decay properties, including half-lives and delayed neutron emission probabilities, are among the most fundamental nuclear-structure data, which are also crucially needed for application purposes, e.g. for calculations of criticality of reactors. The primary aim of this study is to demonstrate that large-scale shell-model calculations are very useful to describe these data. We have calculated β-decay half-lives and β-delayed neutron emission probabilities for 78 nuclei with $13 \le Z \le 18$ and $22 \le N \le 34$ [2]. The experimental values are well reproduced by our calculations, as presented in Fig. 2 for the β-decay half-lives. The quality of our calculation is evaluated by the standard deviation for the ratio of the calculated and experimental data. This value is as small as 1.58 with our calculation, whereas remarkably higher value of 3.04 is given with the standard QRPA calculation [3]. It is expected that the present results will provide more reliable input data for the calculation of r-process nucleosynthesis.

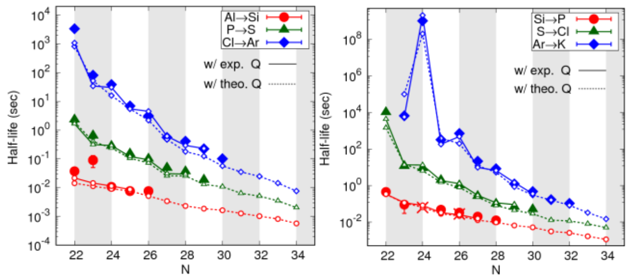

Fig. 2 β-decay half-lives compared between experiment and theory. The filled symbols are experimental data, and the open symbols with the solid and the dashed lines stand for the calculated values using the experimental and calculated Q values, respectively.

References

[1] K. Hirose *et al*., Phys. Rev. Lett. **119**, 222501 (2017).
[2] S. Yoshida, Y. Utsuno *et al*., Phys. Rev. C **97**, 054321 (2018).
[3] P. Möller *et al*., Phys. Rev. C **67**, 055802 (2003).