Research Group for Heavy Element Nuclear Science

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Determination of the limits of stability of heaviest nuclei is one of the topics not only the most interesting but also the most challenging in modern nuclear physics. The produced heaviest elements also open a unique opportunity in chemistry, where chemical/atomic properties are crucially determined by the relativistic effects. The research conducted by our group strongly focusses toward addressing these fundamental questions.

Nuclear fission, a unique physical process observed only in nuclear matter, is our core subject, and understanding of this phenomenon provides the basis for numerous atomic energy applications. Our experimental and theoretical programs include nuclear-structure studies of neutron- and proton-rich nuclei, in addition to super-heavy nuclei. For identifying the chemical properties of the heaviest elements, measurement of the first ionization potential IP_1, as well as the investigation of complex formation and its adsorption behaviour, is promoted to determine the energy and orbitals of the valence electrons.

The highlight of our results in 2018 is the measurement of the IP_1 of Fm (atomic number Z=100), Md (Z=101), and No (Z=102). Combined with our previous report for Lr (Z=103), these results clearly demonstrate that the 5f orbital is fully occupied by electrons at No and that Lr has a weakly bound electron outside the No core [1]. More details are described as a Research Highlight in this Annual Report.

Existence of two deformation paths in the fission of proton-rich nucleus ^{178}Pt (Z=78)

Fission of a proton-rich nucleus has nowadays become a hot topic after the discovery of the mass-asymmetric fission of ^{180}Hg, (see our recent review [2]). Several experimental and theoretical results are revealing that there is a new island which is dominated by the mass-asymmetry in fission in addition to the well-known actinide region in the chart of nuclides. Fission data in the unexplored region were obtained by forming excited compound nuclei in heavy-ion fusion reactions at the JAEA tandem facility. Advantage of this approach is that fission of many nuclides can be investigated by selecting available targets and projectile nuclei, in contrast to the conventional β-delayed fission and/or fission after Coulomb excitation in inverse kinematics.

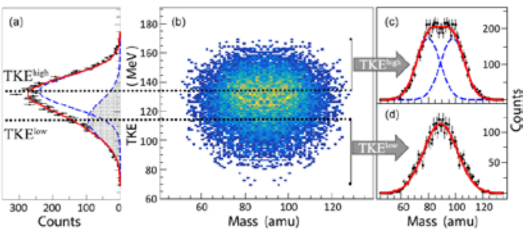

Fig.1 (a) TKE distribution and (b) mass-TKE distribution of the fission of ^{178}Pt, produced in fusion ^{36}Ar+^{142}Nd (E_{beam}=168.8 MeV). (c) and (d) show the fission-fragment mass distributions, generated using high- and low-TKE gates, respectively.

The reaction of ^{36}Ar+^{142}Nd was used to study fission of proton-rich nucleus ^{178}Pt [3]. We found two independent fission modes, i.e., different deformation paths in fission. One is the mass-asymmetric fission leading to average light (L) and heavy (H) fission-fragment masses, A_L/A_H ~79 u /99 u, close to ~80 u /100 u observed in low-energy fission of ^{180}Hg, and the other is the mass symmetric fission, which shows the relatively low total kinetic energy (TKE), (see Fig.1). These two fission modes are well reproduced by nuclear density functional theory.

Origin of the dramatic change of fission mode in fermium isotopes investigated using Langevin framework

About 40 years ago, a very exciting result was found in the spontaneous fissions of fermium isotopes. In contrast to the mass-asymmetric fission of ^{256}Fm and lighter isotopes, ^{258}Fm shows sharp mass-symmetric fission. Sudden appearance of the sharp symmetric fission, only by adding just two extra neutrons, has not been explained quantitatively so far.

The mechanism becomes unveiled clearly using a Langevin framework [4]. The time evolution of the nuclear shape on the potential surface reveals that the lighter fermium isotope ^{254}Fm showing the asymmetric fission-fragment mass distribution is trapped in the local minimum for a substantial length of time before overcoming the saddle point B, (see Fig.2). This behavior changes dramatically in ^{258}Fm that disintegrate immediately after overcoming the 1st saddle point, without surmounting the saddle point B. The fission path is determined by a subtle balance between the saddle point A and B. The second saddle point A, which prevents the fission of ^{254}Fm in this direction, is lowered for ^{258}Fm, opening the compact and sharp symmetric fission.

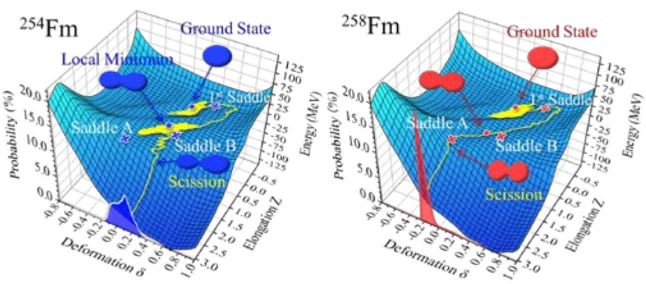

Fig.2 Potential energy landscape for ^{254}Fm and ^{258}Fm, plotted on the deformation and elongation parameters of nuclear shape. Selected sample trajectory typical for each nucleus is shown. ^{254}Fm undergoes fission by overcoming the saddle point B, whereas ^{258}Fm disintegrates through the saddle point A.

References

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