Research Group for Exotic Heavy-Element Nuclear Science

Group Leader : NISHIO Katsuhisa
Members : TSUKADA Kazuaki, ASAI Masato, MAKII Hiroyuki, SATO Tetsuya, HIROSE Kentaro, Riccardo ORLANDI, ITO Yuta, SUZAKI Fumi, James SMALLCOMBE, PHAM Thanh Tung, AOKI Ryota, UCHIBABA Yuta, Gyeongmin GONG, NATORI Hina, MIYACHI Yuta

Determination of the limits of existence of the heaviest nuclei is among the most interesting and challenging topics in nuclear physics. We investigate nuclear structure studies of a broad range of nuclides, in addition to super-heavy nuclei. The heavy elements open unique opportunities for studies of relativistic effects in chemistry and atomic physics.

One of the highlights in FY2022 is establishing a method to study the nuclear structure of neutron-rich heavy nuclei using multinucleon transfer reaction, see Research Highlight. Here, we show two experimental results, i.e. nuclear structure study of selenium isotopes and fission of actinide nuclides.

Mixing of different nuclear shapes in selenium isotopes

The study of nuclear shapes is a key tool for understanding how the Strong Force governs these many-body systems. Of particular interest is the phenomenon of Shape Coexistence, in which multiple different shapes are possible almost simultaneously within a nucleus. Which shape is dominant can switch from one isotope to the next, with the addition of a single neutron. Such a dramatic shape change occurs in the unstable selenium isotopes. Through experimental studies of their shapes, and the quantum mixing between the shapes, we aim to understand how the change is driven, and what determines the point of the shape flip. Nuclear shape affects how the electromagnetic field of a nucleus interacts with the electrons of its own atom. In a process called internal conversion, the energy release in the transition between nuclear shapes can be given to an electron, causing it to break away from the atom. The probability of such transitions is sensitive to shape mixing within the nucleus.

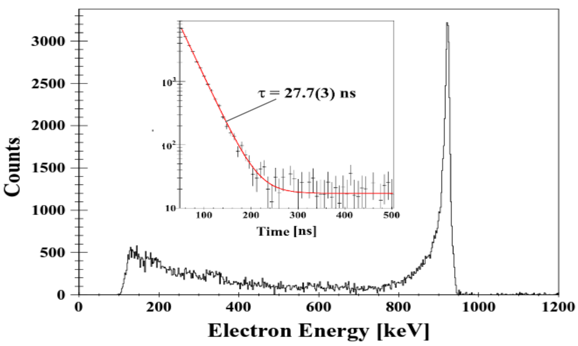

Fig. 1 Electron spectra showing the electron peak at 900 keV for the interaction between two shapes in ^{72}Se and the measured lifetime of the associated process.

Using a dedicated electron spectrometer, called SPICE [1], we measured electron spectra (Fig. 1), and were able to clearly identify the peak corresponding to mixing between shape-coexisting states in the isotope ^{72}Se [2]. Our measurement showed that there is strong mixing between the competing shapes in this nucleus, and while two distinct shapes can be observed in selenium isotope, there isn't a sharp switch of dominant shapes. Furthermore, our experimental work extended to ^{70}Se, for which preliminary analysis supports a description of mixing between three competing shapes, leading to an interesting but complex system which requires further study.

Role of heavy-fragments in the fission of actinide nuclides

Nuclear fission is a unique decay process of heavy nuclei and widely used for atomic energy applications. Also, it is believed that nuclear fission is important to explain the abundance of elements in the universe, as it would happen in the last stage of r-process nucleosynthesis in stars.

We are studying nuclear fission experimentally by populating an excited compound nucleus in multinucleon transfer reactions. This reaction is unique as it can produce many nuclides in one reaction by exchanging different numbers of neutrons and protons between target and projectile nuclei. We are systematically measuring fission fragment mass distributions, known to exhibit mass-asymmetric fission for typical actinide nuclides, as a signature of nuclear shell structure characterizing fission process.

Figure 2 shows the average heavy (A_H) and light fragment mass numbers (A_L) obtained in our experiments. In general, the heavy fragments maintain A_H~140, whereas the light fragment linearly increases with the mass number of fissioning nucleus (A_c). Looking in detail, it is noticed that not only A_L but also A_H increases with A_c for each elemental isotopes. Assuming that proton to neutron ratio of fissioning nucleus is conserved in fragments, we found that heavy fragments have an average nuclear charge Z_H=54 for all the studied nuclei, indicating a dominant role in fission.

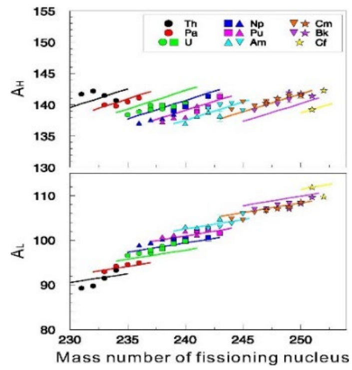

Fig. 2 Average heavy (A_H) and light (A_L) fragments as a function of the mass number of fissioning nucleus.

References

[1] M. Moukaddam, J. Smallcombe et al., Nuc. Inst. Meth. A, 905, 180-187, (2018).
[2] J. Smallcombe et al., Phys. Rev. C, 106, 014312, (2022).
[3] K. Hirose et al., TASCA 23, 20th Workshop on Recoil Separator for Superheavy Element Chemistry & Physics, 25-27 April 2023 Darmstadt, Germany.