Research Group for Reactions Involving Heavy Nuclei

Group Leader : A. Andreyev
Members : K.Nishio, I. Nishinaka, H. Koura, Y. Utsuno, H. Makii, K. Hirose, R. Orlandi, R. Léguillon, J. Smallcombe, E. Maeda

Shell structure of nuclei has substantial effects on their masses, decays and nuclear reactions. The research objective of the group is to study the evolution of shell structure in exotic heavy nuclei. For this purpose, nuclear decay properties of the exotic nuclear system and reaction process are investigated experimentally and theoretically. Nuclear fission process in the new region of chart of nuclei is investigated to find new effects of shell structure and dynamics dominating fission process. Nuclear structure study for neutron- and proton-rich nuclei are also our scope.

Study for fission of neutron-rich actinide nuclei using multi-nucleon transfer reaction

Nuclear fission is a fundamental process for nuclear energy applications. Finding new phenomena in fission and understanding of the fission process would bring new idea to solve issues related to reactor safety and transmutation of long lived nuclear waste. We are measuring fission properties for neutron-rich actinide nuclei for this purpose.

In order to access neutron-rich nuclei, multi-nucleon transfer reactions with actinide target nuclei are used. Here, we report on the results obtained in the reaction $^{18}O + ^{232}Th$. The experiment was carried out at the JAEA tandem facility. A ^{232}Th target was irradiated by ^{18}O beams. Projectile-like nuclei produced by multi-nucleon transfer reaction were identified using silicon ΔE-E detectors, and the fissioning nuclei and their excitation energy were assigned event by event. Both fission fragments were detected in coincidence with position-sensitive multi-wire proportional counters, and the fragment masses are determined by kinematic consideration.

In the reaction of $^{18}O + ^{232}Th$, we obtained fission data for at least 14 nuclei ranging from actinium to uranium isotopes [1]. Figure 1 shows the fission fragment mass distributions for several protactinium isotopes, where data for three neutron-rich nuclei $^{234,235,236}Pa$ were obtained for the first time.

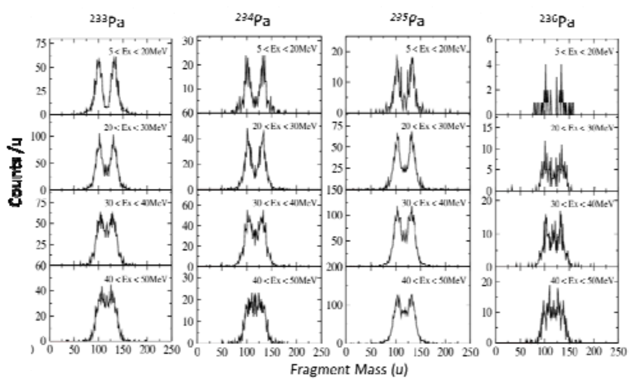

Fig.1 Fission fragment mass distribution for protactinium isotopes produced by multi-nucleon transfer reaction $^{18}O + ^{232}Th$. For each nuclei, excitation energy dependence is shown.

The figure also shows the excitation energy dependence of the mass distributions. Transition from mass-asymmetric fission to symmetric fission toward high excitation energy is obtained. The data are also useful to determine the distribution of reaction products generated in collisions between heavy nuclei.

Finding a New Magic Number 34 from the Level Structure of ^{54}Ca

Searching for the appearance of new magic numbers and the disappearance of conventional magic nubers is one of the central issues in the physics of exotic nuclei. Since we predicted the existence of a new magic number (N) 34 in a very neutron-rich nucleus ^{54}Ca about a decade ago [2], a number of experiments have been carried out to verify the prediction. Experimental data for its surrounding nuclei do not show any signs of the existence of the N=34 magic number, and therefore the direct experiment on ^{54}Ca has been strongly awaited. In this study, the 2^+_1 energy level in ^{54}Ca is measured for the first time via the in-beam γ-ray spectroscopy at RIBF in RIKEN [3]. The measured energy, as well as the ones for other calcium isotopes, is presented in Fig. 2. The 2^+_1 level in ^{54}Ca is much higher than the ones for non-magic nulclei with N=22, 24, 26, 30, and is almost equivalent to that of a semi-magic nucleus ^{52}Ca. Our shell-model calculation shows that the 2^+_1 level in ^{54}Ca indicates a large sub-shell gap between the $p_{1/2}$ and $f_{5/2}$ orbits which amounts to approximately 2.5 MeV. This is much larger than sub-shell gaps in nickel isotopes which is typically less than 1 MeV. This experiment has thus confirmed our prediction and has also validated the underlying mechanism of the evolution of shell structure due to the nuclear force.

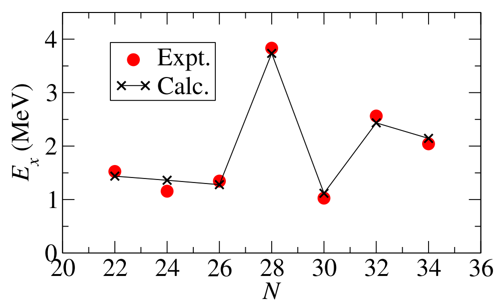

Fig.2 The 2^+_1 levels in calcium isotopes compared between experiment (Expt.) and shell-model calculations (Calc.).

References

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[2] T. Otsuka, R. Fujimoto, Y. Utsuno *et al.*, Phys. Rev. Lett. **87**, 082502 (2001).
[3] D. Steppenbeck *et al.*, Nature **502**, 207 (2013).