Research Group for Reactions Involving Heavy Nuclei

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Shell structures of nuclei have substantial effects on their masses, decays and nuclear reactions. The research objective of the group is to study the evolution of shell structures in exotic heavy nuclei. The nuclear decay properties of these nuclei are investigated experimentally and theoretically. After finding a new type of asymmetric fission in a proton-rich nucleus ^{180}Hg, our group has been pursuing fission studies for neutron and proton-rich nuclei in the region from mercury to very-heavy elements as well as new shell phenomena in proton- and neutron-rich nuclei.

Observation for ß-delayed fission for proton rich astatine and bismuth nuclei

Beta-delayed fission is defined as fission from the excited states of nuclei populated by the ß/EC decay of parent nucleus. The ß-delayed fission probability is ruled by the balance between the *Q*-value of ß-decay and the fission barrier height. Followed by our definitive finding of ß-delayed fission of ^{180}Tl (fission of ^{180}Hg) in the region of proton-rich lead nuclei, we have newly observed ß-delayed fission of ^{192,194}At (fission of ^{192,194}Po) and ^{186,188}Bi (^{186,188}Pb) [1]. These nuclei are produced by fusion-evaporation reactions using heavy-ion beams supplied by the linear accelerator at GSI (Darmstadt, Germany). These nuclei are separated in flight by using a velocity filter (SHIP) and implanted into a silicon detector, where the fission fragments were detected. We started to measure the mass distributions of ß-delayed fission fragments using radioactive astatine beams. During the beam development to extract unstable astatine beams, the first ionization potential of astatine was measured to be 9.317510(8) eV for the first time by observing Rydberg states with a laser ionization spectroscopy [2] (Fig.1).

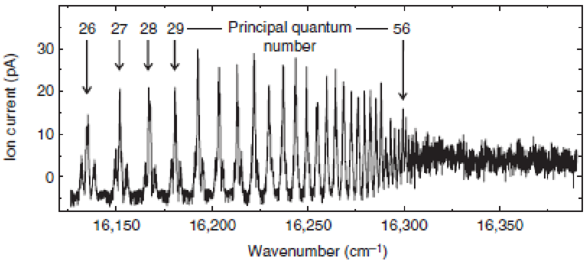

Fig.1 Laser scan of the ionization laser across the ionization threshold of At. Rydberg lines are observed.

Prediction of doubly-closed shell nuclei in a superheavy mass region

The limit of existence of nuclei is essentially determined by their shell structures of nuclei. A single-particle level calculation using a modified Woods-Saxon potential model was extended to the extremely superheavy mass region. We found that neutron (*N*) and proton (*Z*) shell closures still remain for up to N = 308 and Z = 164, respectively. In the calculation, seven unknown doubly magic spherical nuclei beyond ^{208}Pb were predicted. Of these, $^{298}Fl_{184}$ (Z=114) and $^{472}[164]_{308}$ are beta-stable nuclei. The nucleus $^{472}[164]_{308}$ is the heaviest doubly magic nucleus, which decays by emitting α particle with 250 seconds half-life ($T_{1/2}$). The most long-lived nucleus among the seven doubly magic nuclei is $^{298}Fl_{184}$, which is also the α-decaying nucleus with $T_{1/2}$= 12.4 days (Fig.2) [3].

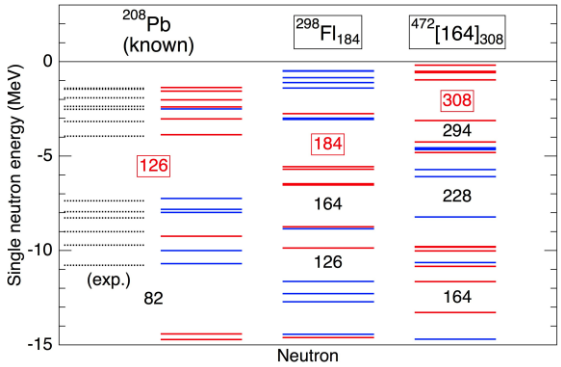

Fig.2 Single-neutron levels for ^{208}Pb, ^{298}Fl, and ^{472}[164] nucleus.

Large deformation in the ^{42}Si nucleus

The shell structure of nuclei changes rather drastically in going from stable to unstable nuclei, and even the ordinary magic numbers can be altered. The N = 28 magic number constitutes a good example. This magic number is considered to disappear for the $^{42}Si_{28}$ nucleus because of its low 2^+_1 level. In the present study [4], the origin of the disappearance is investigated with shell-model calculations. The calculation shows that the proton shell gap among the 1*s*-0*d* shell is quenched due to the tensor force, causing a large deformation and resulting low 2^+_1 level in ^{42}Si as shown in Fig. 3. This onset of deformation named "tensor-force driven Jahn-Teller effect" might be widely seen in the nuclear chart including heavy nuclei.

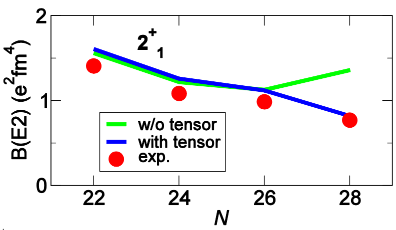

Fig. 3 2^+_1 levels in Si isotopes compared between experiment (red circles) and theory (lines). The blue and green lines stand for calculations with and without the tensor force, respectively.

References

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[4] Y. Utsuno *et al*., Phys. Rev. C **86**, 051301(R) (2012).