Beta-decay properties of neutron-rich Zr isotopes studied by the Skyrme energy-density functional method†

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The study of unstable nuclei has been a major subject in nuclear physics for a couple of decades. The collective mode of excitation emerging in the response of the nucleus to an external field is a manifestation of the interaction among nucleons. Thus, the spin-isospin channel of the interaction and the spin-isospin part of the energy-density functional (EDF), which is crucial for understanding and predicting the properties of unstable nuclei and asymmetric nuclear matter, have been studied in much detail, especially through Gamow-Teller (GT) strength distributions.

The GT strength distribution has been extensively investigated experimentally and theoretically not only because of interest in the nuclear structure but also because β-decay half-lives set a time scale for the rapid-neutron-capture process (r-process), and hence determine the production of heavy elements in the universe. The r-process path is far away from the stability line, and involves neutron-rich nuclei. They are weakly bound and many of them are expected to be deformed according to the systematic Skyrme-EDF calculation[1)].

Recently, β-decay half-lives of neutron-rich Kr to Tc isotopes with $A \simeq 110$ located on the boundary of the r-process path were newly measured at RIBF[2)]. The ground-state properties such as deformation and superfluidity in neutron-rich Zr isotopes up to the drip line have been studied by employing the Skyrme-Hartree-Fock-Bogoliubov (HFB) method, and it has been predicted that Zr isotopes around $A = 110$ are well deformed in the ground states[3)].

To investigate the GT mode of excitation and β-decay properties in the deformed neutron-rich Zr isotopes, we construct a new framework of the deformed HFB + proton-neutron QRPA employing the Skyrme EDF self-consistently in both the static and dynamic levels. Furthermore, the HFB equations are solved in real space for a proper description of the pairing correlations in weakly bound systems and coupling to the continuum states.

The $T = 0$ pairing interaction is effective for the GT excitation in systems where the ground states have the $T = 1$ pairing condensates. In the neutron-rich Zr isotopes under investigation, we find that the $T = 0$ pairing interaction enhances the low-lying GT strengths. The low-lying GT strength distribution strongly affects the β-decay rate. Thus, we can clearly see the effect of $T = 0$ pairing in the β-decay life time. We can calculate the β-decay half-life $T_{1/2}$ with Fermi's golden rule by using the GT strength distributions microscopically obtained in the self-consistent pnQRPA framework.

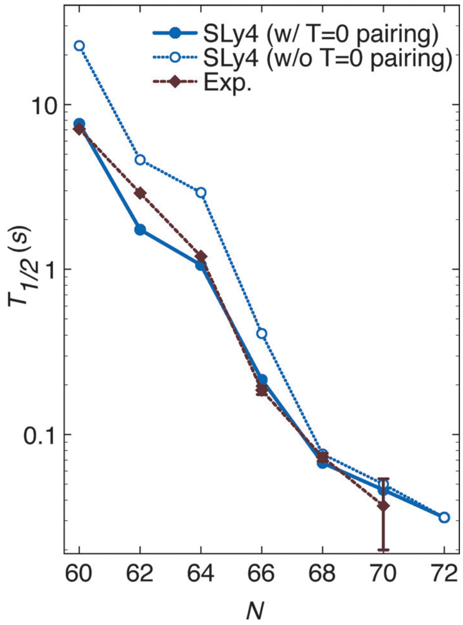

Fig. 1. Experimental and theoretical β-decay half-lives of the Zr isotopes, calculated by employing the SLy4 EDF combined with and without the $T = 0$ pairing interaction.

Figure 1 shows the β-decay half-lives of the Zr isotopes calculated with the SLy4 EDF combined with and without the $T = 0$ pairing interaction. We see that the attractive $T = 0$ pairing interaction substantially shortens the β-decay half-lives. β-decay rates depend primarily on the Q_β value, the residual interactions in both the p-h and p-p channels, and the shell structures. The framework developed here self-consistently treats these key ingredients on the same footing. Once the strength of the $T = 0$ pairing interaction is determined so as to reproduce the observed β-decay half-life of ^{100}Zr, our calculation scheme well produces the isotopic dependence of the half-lives up to ^{110}Zr as was recently observed at RIBF.

References
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