論文の内容の要旨

論文題目: Beta-decay spectroscopy on neutron-rich Nuclei in a range of Z = 26 － 32

(中性子過剰な Z=26-32 核のベータ核分光)

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This thesis reports on an experimental work studying the β-decay properties in the neutron-rich nuclei around ^{78}Ni. From this work, half-lives of 38 neutron-rich nuclei were deduced including 13 new half-lives of $^{72-74}$Fe, $^{76-77}$Co, $^{79-80}$Ni, $^{81-82}$Cu, ^{84}Zn, ^{87}Ga and $^{87-88}$Ge. Besides, 10 β-delayed neutron emission probabilities (P_n) were measured around ^{78}Ni, in which the P_n values of ^{78}Ni, $^{80-81}$Cu, $^{83-84}$Zn, and ^{85}Ga were deduced for the first time. Based on the new measured half-lives and P_n values, shell evolution at Z = 28 and N = 50 were discussed in the vicinity of ^{78}Ni.

The nuclide of ^{78}Ni is remarkably interesting because of its possibility to be the most neutron-rich doubly-magic nuclide known so far. Recent studies on both experiments and theories suggest a shell quenching of Z = 28 and a robust shell closure of N = 50 in ^{78}Ni. Thus, many works have been motivated to give direct evindence for the magicity of ^{78}Ni. Among the available approaches exploring the nuclear structure in exotic nuclei, study of the β-decay properties is often the first means of identifying a new nuclear species and hence also the first harbinger of a knowledge of its properties. Once the existence of a particular nucleus is demonstrated, even a measurement of the β-decay half-life or the P_n value with a limited production yield can provide important clues to its properties. Since

both half-life and P_n value are integrated quantities by summing transition rates over all the possible final states in daughter nucleus located inside corresponding energy windows, they are regarded as sensitive probes to reflect properties of neutron-rich nuclei such as the β-decay energy window Q_β (the isoberic mass difference between the parent and daughter nuclei), the energy distribution of β-strength function, the neutron separation energy. Those information, in turn, benchmark the key ingredients in nuclear-structure theories such as single-particle energies and effective interactions, which are located at extremely neutron excess and closer to the neutron drip line for the unique case of ^{78}Ni.

In order to study the neutron-rich nuclei by means of the decay spectroscopy in the vicinity of ^{78}Ni, the experiment was performed at the RIBF facility. A high-intensity primary beam of ^{238}U was accelerated up to an energy of 345 A MeV by the RIKEN cyclotron accelarator complex before impinging on a 3-mm-thick (0.56 g/cm^2) ^{9}Be target to produce the secondary beam by in-flight fission. The nuclei of interests were separated by the first stage of BigRIPS from the secondary beam consisted of a cocktail of neutron-rich nuclei. Then, an event-by-event particle identification (PID) was carried out based on the ΔE-$B\rho$-TOF method, in which the energy loss, the magnetic rigidity and the time of flight are measured by using the combination of the second stage of BigRIPS and ZeroDegree spectrometer (ZDS), giving the atomic number Z and the mass-to-charge ratio A/Q for all the fragments transmitted through BigRIPS and ZDS. The ^{238}U^{86+} beam was delivered at an average current of 430 nA (5 pnA) at the production target during the 14 days of beam time, allowing for determinations of more than 10 new half-lives in the vicinity of ^{78}Ni.

A highly segmented silicon stopper array, WAS3ABi (Wide-range Active Silicon Strip Stopperr Array for Beta and ion detection), was placed after the end of ZDS for the implantation of heavy ions as well as the detection for the emitted β particles. Eight layers of double sided silicon strip detectors (DSSSD) were mounted inside the WAS3ABi chamber to fully cover the stopping range of the nuclei of interest in the secondary beam. Each silicon detector had a thickness of 1 mm and an active area of 60 $\times$ 40 mm^2, which was segmented into 60 strips horizontally on the front side and 40 strips vertically on the back side. The granularity of the silicon stopper helps for a precise position measurement for the implanted fragments and emitted β particles, based on which a position correlation can be applied to construct the ion-β association. The β-decay half-life is then deduced

by measuring the time difference between an implanted fragment and associated β decays. Because of the radioactivity of the daughter nuclei produced by the β decay, decay curve built by the ion-β correlation is contributed not only by the parent nucleus but also by the daughter nucleus, the grand-daughter nucleus, and so on. The fitting analysis to the decay curve such built needs to consider many components and, therefore, the obtained half-life is usually accompanied by large systematic uncertainty.

In order to verify the validity and reliability of the half-life deduce with such ion-β correlation, the EURICA (EUROBALL-RIKEN Cluster Array) γ-ray detectors array, consisting of 12 EUROBALL cluster Ge detectors, was mounted surrounding the WAS3ABi stopper to detect the γ rays emitted following a β decay. Thanks to the high energy resolution and signal to background ratio of the γ-ray detectors , the coincident measurement between the implantations, emitted β particles, and delayed γ rays greatly reduce the backgound level in the β-decay spectrum and simplified the structure of decay curve and, therefore, reduce the systematic error in the final result. Comparison between the half-lives obtained with and without γ-ray coincidence shows a nice consistency with each other. Furthermore, the half-lives measured by the present experiment well agreed with the data from literature reported by previous works. All the consistencies achieved by the results suggest a reasonable analysis for the very neutron-rich nuclei, of which the production yield is so weak that only the ion-β correlation were available to determine the β-decay half-lives. Another main purpose of employing the γ-ray detectors into the experiment is to measure the P_n values based on the intensity of β-delayed γ peak from daughter nuclei observed after the implantation of parent nuclei.

Figure 1 shows the systematics of the β-decay half-lives as a function of neutron number for $Z = 26 - 33$, which includes not only the newly measured half-lives but also the ones from literature. According to the figure, the relatively shorter half-life of $^{79-80}$Ni compared with the systematic trend at $N \leq 50$ suggests a shell gap effect of $N = 50$ in the $_{28}$Ni isotope. However, this half-life reductions in the $N = 51$ isotones become much less stronger in the isotopes with $Z \geq 30$, indicating a possible enhanced magicity of $N = 50$ at $Z = 28$ than that at $Z \geq 30$. Another noticeable systematics in Fig. 1 is the large half-life gaps between the $_{27}$Co and $_{28}$Ni isotopes emerging systematically at $N = 44 - 50$. This gap can be understood by the large difference in the Q value released in the β decays between the $_{27}$Co and $_{28}$Ni isotopes. The difference in Q value

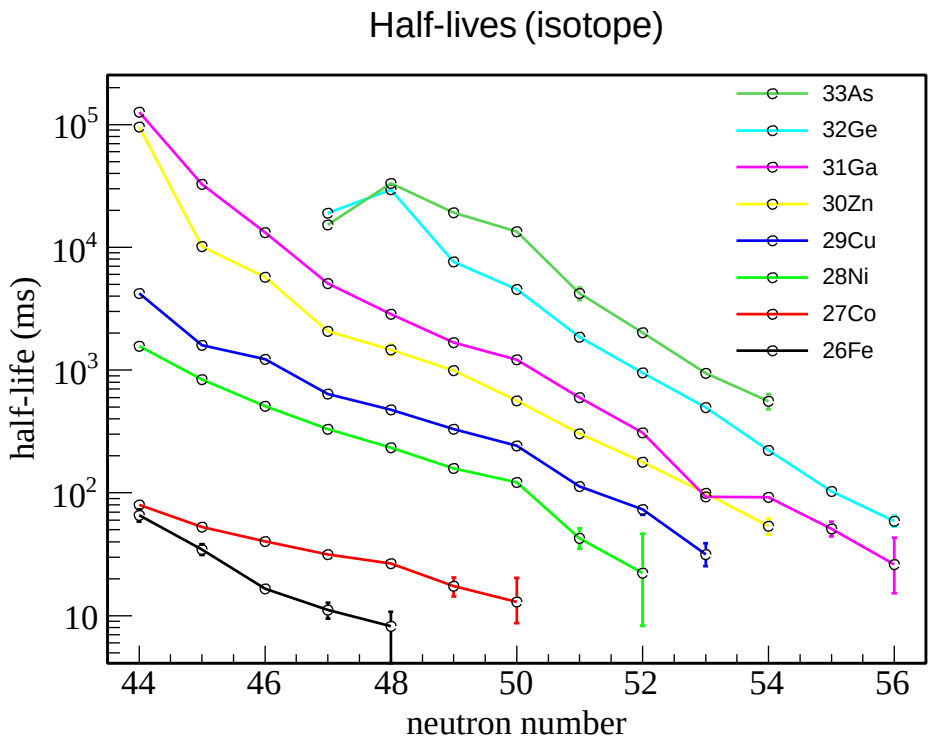

Figure 1: Systematics of β-decay half-lives as a function of neutron number for isotopes $Z = 26 - 33$. All the points are experimental data which are either taken from literature or this work.

is expected to be produced by the energy gap between the $\pi f_{7/2}$ single particle orbit (SPO) and $\pi f_{5/2}$ SPO, which span the spin-obital splitting shell gap of $Z = 28$. Since the half-life is approximately proportional to the minus fifth power of the Q value, the strong gap in the half-lives between $_{27}$Co and $_{28}$Ni isotopes suggests a sizable shell gap of $Z = 28$ in $N = 44 - 50$.

Half-lives and P_n values deduced from this work are compared with various models including microscopic and macroscopic global models as well as the interacting shell model. Unfortunately, none of the model included in the discussion can provide predictions with universal consistencies. The inconsistencies between the experimental results and theories require a detailed study into each model to address the insufficient considerations to improve the description of the β-decay properties in this region and the predictive powers of the theoretical models for the unknown region.