Constraining multi-neutron emission models with spectroscopy of neutron-rich Ga isotopes using BRIKEN array

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As we move further from the line of β-stability towards the neutron drip line, Q_β values become larger than the two-neutron separation energy (S_{2n}), which allows multi-neutron emissions after β-decay. In the neutron-rich nuclei along the astrophysical r-process path, multi-neutron emissions are considered to be dominant decay modes.[1)] The numbers of neutrons emitted in the β-decays of exotic nuclei modify the decay path back to stability and affect the final abundance calculation. However, experimental data that enable the evaluation of multi-neutron emissions for the r-process nuclei are almost non-existent. Until quite recently, theoretical predictions of the neutron emission branching ratio (P_n) were based on a cut-off model that assumes only the higher-multiplicity neutron emission prevails in the energy regions open to multiple neutron-emission channels. In order to include the competition of one-neutron emission from the states above S_{2n}, Kawano *et al.* developed a Hauser-Feshbach statistical model calculation.[2)]

We studied neutron-rich Ga isotopes by means of β-n-γ spectroscopy at RIBF using the high-efficiency neutron counter array BRIKEN,[3–5)] with two Ge clover detectors. The result that one-neutron emission is dominant for all the four Ga isotopes was interpreted as competition in one-neutron emission among two-neutron unbound states, and we demonstrated that the inclusion of the statistical model reproduces the branching ratio better than the cut-off model.[6)]

Recently, we analyzed γ-ray spectra of the decay of $^{84-87}$Ga. Figure 1 shows γ spectra gated by the neutron multiplicity of the BRIKEN array for the decay of ^{86}Ga. γ rays from ^{84,85,86}Ge are clearly identified in the $2n$, $1n$, and $0n$ gated spectra. The $2^+ \rightarrow 0^+$ γ ray from ^{84}Ge in the two-neutron branches was observed at 624 keV. The intensity of the 624-keV γ ray per 100 two-neutron decays was 37(8)%. We performed our Hauser-Feshbach statistical model calculation by using the strength distribution and level densities from shell-model calculations. This model was used to validate the measurement of the neutron spectra in the decay of ^{83,84}Ga.[7)] The shell model produced less states below S_{2n} than the number of the default levels generated by the statistical model using the Gilbert-Cameron formula. When known, the low-lying states in the decay daughters calculated by the shell model were replaced with experimental data. Compared with the feeding of the experimental 624-keV state in ^{84}Ge, the statistical model predicted the γ intensity as 33%, which is in good agreement with the experimental value we measured. The statistical model also reproduced the γ branching ratio of other γ rays in the decay. The detailed β-n-γ analysis of other neutron-rich Ga isotopes is in progress.

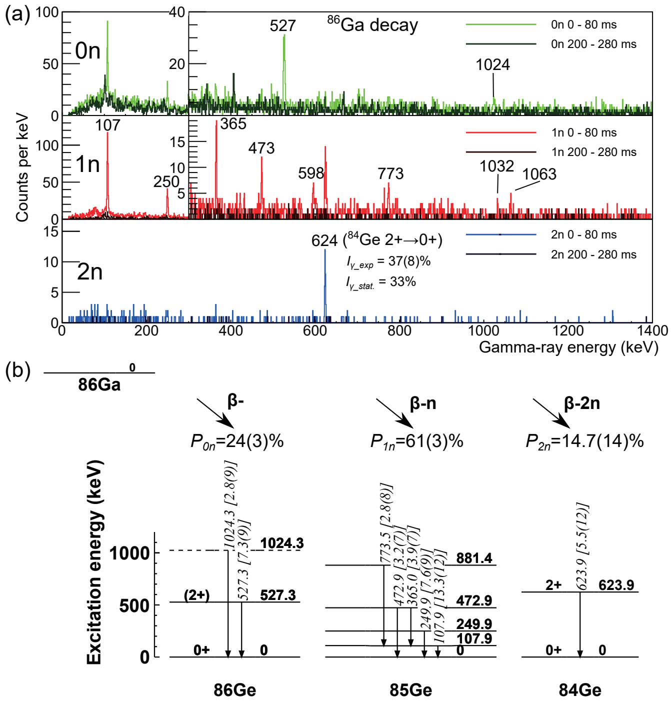

Fig. 1. (a) γ-ray spectra of the decay of ^{86}Ga gated by neutron multiplicities in the BRIKEN array. (b) Decay scheme. γ branching per 100 decays is shown in the square brackets.

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