# Study of $\beta$-delayed one-neutron emission probabilities using a neural network model†

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The $\beta$-delayed neutron emission is a key ingredient in astrophysical $r$-process nucleosynthesis, whose theoretical model predictions still contain large uncertainties. In this work, we applied a novel feed-forward neural network (FNN) model to accurately calculate $\beta$-delayed one-neutron emission probabilities.

We considered a three-layer FNN architecture consisting of input, hidden, and output layers with $N_{in}$, $N_h$, and $N_o$ neurons, respectively. The model was trained with a set of input data of known physical quantities, namely, one-neutron emission $Q$-value, $Q$-value difference between the one- and two-neutron emissions, $\beta$-decay half-life, $T_{1/2}$, the distance from the least neutron-rich nucleus with $Q_{\beta 1n} > 0$ in each isotope, $N - N_D$, and the exponential form of the ratio of $Q$-value, $\exp(-Q_{\beta 2n}/Q_{\beta 1n})$. The learning process was performed to minimize the loss function via proper optimization methods. We used the root mean squared prop (RMSProp) method to obtain the optimal network parameters.

First, we calculated the one-neutron emission probabilities, $P_{1n}$, of the nuclei, which have only one-neutron emission channels. The input data contain 127 nuclei and the size of the training set is 89. The following inputs are given in the network: $Q_{\beta 1n}$, $\Delta E_w^3 T_{1/2}$, $\mathcal{G}(Z,N) = \Delta E_w \Delta S_{2n}$, and $N - N_D$, where $\Delta E_w = Q_{\beta 1n} - Q_{\beta 2n}$ is actually $Q_{\beta 1n}$ in this special case, and $\Delta S_{2n} = S_{2n}(Z+1,N) - S_{2n}(Z+1,N-2)$. The input, hidden, and output layers contain 4, 40, and 1 neurons, respectively. The $P_{1n}$ differences between the present ML-FNN and experimental data of these nuclei are shown in Fig. 1, together with those obtained by the FRDM12+(Q)RPA+HF[1)] and RHB+RQRPA models.[2)] It can be observed that the results of the three models are reasonable consistent with the experimental data. The differences between ML-FNN and experimental data are distributed over $-25\%$ to $25\%$ and densely concentrated around 0, especially when $N > 40$. The RMSD values of ML-FNN are 8.5% and 9.0% for the training and for testing sets, respectively, and 11.8% and 13.4% for the FRDM12+(Q)RPA+HF and RHB+RQRPA models, respectively. A remarkable improvement of ML-FNN model can be seen in the RMSD compared to the other two models.

The waiting-point nuclei are the key elements to determine the time scale of $r$-process and strongly affect the final abundance of elements in the solar system. The experimental and theoretical $P_{1n}$ values of the waiting-point nuclei at the magic neutron numbers $N = 50$ and 82 are listed in Table 1. It can be observed that the proposed ML-FNN model provides the $P_{1n}$ values of the waiting-point nuclei at $N = 50$ and 82 with the highest accuracy, both qualitatively and quantitatively.

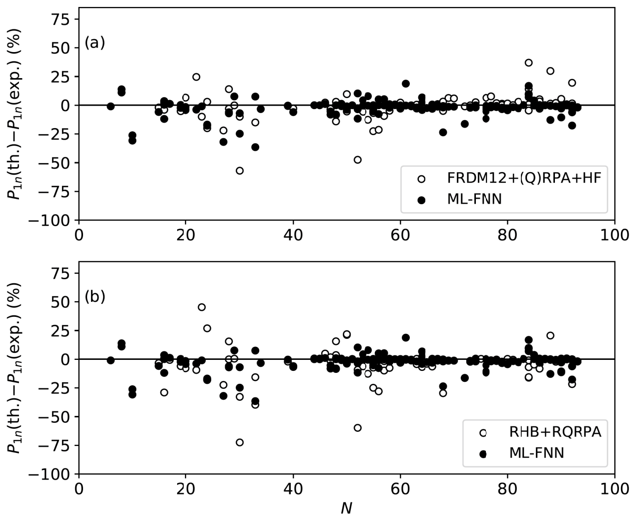


Fig. 1. Differences of $P_{1n}$ between theoretical results and experimental data for the nuclei, which have only one-neutron emission channels. The data of FRDM12+(Q)RPA+HF and RHB+RQRPA are taken from Refs. 1) and 2), respectively.

Table 1. $P_{1n}$ of waiting-point nuclei at magic neutron numbers $N = 50$ and 82. Three theoretical models, FRDM12+(Q)RPA+HF,[1)] RHB+RQRPA,[2)] and ML-FNN, are listed with experimental data with errors in the brackets. The values are given in %.

| Nuclides | FRDM12 | RHB | ML-FNN | Exp. |
|---|---|---|---|---|
| $^{79}_{29}$Cu$_{50}$ | 30.0 | 56.5 | 40.1 | 66(12) |
| $^{80}_{30}$Zn$_{50}$ | 11.0 | 22.5 | 1.6 | 1.36(12) |
| $^{81}_{31}$Ga$_{50}$ | 7.0 | 34.3 | 14.1 | 12.5(8) |
| $^{128}_{46}$Pd$_{82}$ | 9.0 | 1.8 | 11.8 | 10(7) |
| $^{129}_{47}$Ag$_{82}$ | 10.0 | 13.2 | 21.2 | 17.9(14) |
| $^{130}_{48}$Cd$_{82}$ | 6.0 | 0.7 | 1.6 | 3.0(2) |

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References

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