# First direct mass measurement for neutron-rich $^{112}$Mo with the new ZD MRTOF-MS[†]

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Some theoretical models predict that a harmonic oscillator gap might emerge at $N = 70$, and the classical shell gap would quench at $N = 82$[1)] in the very neutron-rich region. As experiments show, the $\gamma$-ray spectroscopy,[2)] lifetime measurements of first $2^+$ ($2_1^+$) states,[3)] and $\beta$-decay half-life measurements[4)] in this mass region do not support the appearance of the $N = 70$ shell and the quenching of the $N = 82$ classical shell. As an additional observable, atomic mass data can provide evidence for shell or sub-shell closures because the separation energy of nucleons beyond a closed shell or sub-shell will change significantly. In this study, the atomic masses of $^{111,113}$Ag, $^{111-113}$Pd, $^{111-113}$Rh, $^{111-113}$Ru, and $^{111,112}$Mo were measured during the online commissioning experiments of the ZeroDegree spectrometer Multi-Reflection Time-Of-Flight Mass Spectrograph (ZD MRTOF-MS).

The mass measurements were conducted in symbiotic experiments with non-destructive in-beam $\gamma$-ray spectroscopy measurements[5)] at the RIBF of the RIKEN Nishina Center in Japan. The isotopes of interest were produced by in-flight fission of a 345 MeV/nucleon $^{238}$U primary beam. A 740 mg/cm$^2$ $^9$Be target was used, and the in-flight fission fragments were selected and transported using the BigRIPS Separator. A secondary target was employed for specific nucleon knock-out reactions. Unreacted secondary beam and reaction products from the secondary target were further transported through the ZeroDegree spectrometer and available for study with the ZD MRTOF-MS setup.[6)]

The mass of $^{112}$Mo (mass excess: $-57470\,(8)$ keV) has been determined for the first time. The atomic mass of $^{112}$Rh[7)] determined by the JYFLTRAP group, previously excluded by the AME2020, has been confirmed. A good agreement was observed between our results and the AME2020 except for $^{112}$Rh; the mass resolving power reached $\approx 5 \times 10^5$. Combined with the AME2020 mass values and our results, we studied the two-neutron separation energy (see Fig. 1) in the mass region of $A = 110$. From these data, we conclude that up to $^{112}$Mo, no stabilizing shell effect corresponding to the harmonic oscillator gap at $N = 70$ exists. To further study the shell evolution, we require additional data toward the neutron drip-line.

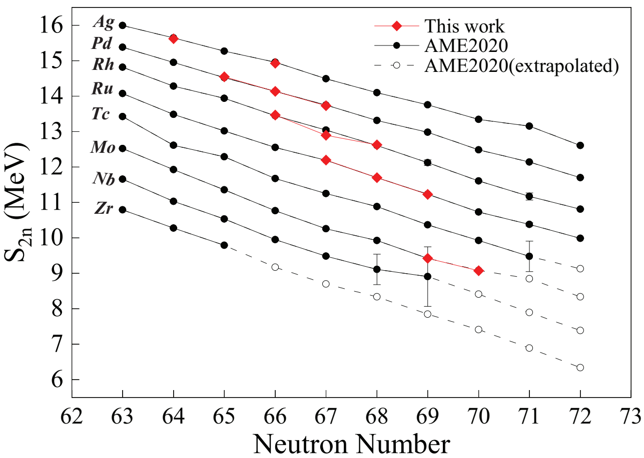


Fig. 1. Two-neutron separation energies for isotopic chains from Zr to Ag. The values from this study and AME2020 are marked in red and black, respectively. Extrapolated values from trends of the mass surface (TMS, see AME2020) are shown as open circles.

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† Condensed from the article in Phys. Rev. C. **108**, 054312 (2023)

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DOI:10.34448/RIKEN.APR.57-159