# Discovery of $^{39}$Na[†]

D. S. Ahn,[*1] J. Amano,[*3] H. Baba,[*1] N. Fukuda,[*1] H. Geissel,[*5] N. Inabe,[*1] S. Ishikawa,[*4] N. Iwasa,[*4] T. Komatsubara,[*1] T. Kubo,[*1] K. Kusaka,[*1] D. J. Morrissey,[*6] T. Nakamura,[*2] M. Ohtake,[*1] H. Otsu,[*1] T. Sakakibara,[*4] H. Sato,[*1] B. M. Sherrill,[*6] Y. Shimizu,[*1] T. Sumikama,[*1] H. Suzuki,[*1] H. Takeda,[*1] O. B. Tarasov,[*6] H. Ueno,[*1] Y. Yanagisawa,[*1] and K. Yoshida[*1]

The location of the neutron dripline provides a key benchmark for advanced nuclear models and theories. It reflects the details of the underlying nuclear structure and interactions, which include the evolution of the nuclear shell property and associated nuclear deformation. Thus, locating the neutron dripline experimentally provides a significant key to understanding the nuclear structure under extremely neutron-rich conditions.

In our previous study,[1)] we searched for the new isotopes $^{32,33}$F, $^{35,36}$Ne, and $^{38,39}$Na to investigate the neutron dripline at fluorine (atomic number $Z = 9$), neon ($Z = 10$), and sodium ($Z = 11$). No events were recorded for $^{32,33}$F, $^{35,36}$Ne, and $^{38}$Na and only one event was recorded for $^{39}$Na. This enabled us to determine the neutron dripline for fluorine and neon to be $^{31}$F and $^{34}$Ne, respectively, nearly 20 y after $^{24}$O was confirmed as the dripline nucleus of oxygen ($Z = 8$).

In this study,[2)] we conducted a new experiment dedicated to searching specifically for $^{39}$Na to establish that it is particle-bound. The new isotope $^{39}$Na has the mass number $A = 3Z + 6$, located beyond the previously known most neutron-rich isotope $^{37}$Na, which was discovered 20 y ago;[3)] see Fig. 1. It is a strong candidate to be the dripline nucleus of sodium, and establishing its existence provides a significant extension of the neutron dripline and a benchmark for nuclear structure calculations as well as nuclear mass models. It should be noted that $^{39}$Na has the neutron number $N = 28$, which is normally a magic number.

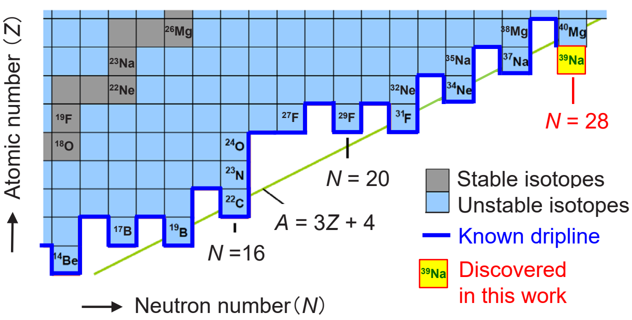


Fig. 1. Section of the nuclear chart indicating the location of the $^{39}$Na isotope discovered in this study.

The search was conducted at the RIKEN RIBF using projectile fragmentation of an intense $^{48}$Ca beam at 345 MeV/nucleon on a 20-mm-thick beryllium target. The projectile fragments including $^{39}$Na were separated and identified in flight by the large-acceptance two-stage fragment separator BigRIPS.[4,5)] The intensity of the $^{48}$Ca beam was as high as ∼540 particle nA.

The particle identification was made at the second stage of the BigRIPS separator, relying on the combination of time of flight (TOF), magnetic rigidity ($B\rho$), and energy loss ($\Delta E$) measurements, from which the $Z$ and $A/Z$ values were deduced for each fragment. The TOF was measured between two thin plastic scintillators installed at the intermediate and final foci of the second stage. The value of $\Delta E$ was measured using a stack of six identical silicon semiconductor detectors installed at the final focus. The value of $B\rho$ was determined from a position measurement at the intermediate focus using the plastic scintillator that also measured the TOF. The separator setting was tuned for the optimal transmission of $^{39}$Na. The production of $^{36}$Ne was also revisited with another separator setting tuned for that of $^{36}$Ne to improve the confidence level that $^{34}$Ne is the dripline nucleus of neon.

After extensive running, we observed nine events for $^{39}$Na and clearly established that the $^{39}$Na nucleus is particle-bound. Furthermore, no events were observed for $^{35,36}$Ne, which is consistent with their particle instability established in our previous work. The measurement enabled us to significantly improve the confidence level and hence firmly determine that $^{34}$Ne is the dripline nucleus.

The particle stability of $^{39}$Na, established by the present discovery, suggests the occurrence of nuclear deformation in $^{39}$Na, as it induces more stability to the nuclear binding. $^{39}$Na could be particle-bound as its ground state is deformed, suggesting the loss of the $N = 28$ magicity at sodium. This interpretation is supported by the recent state-of-the-art large-scale shell model calculation with *ab initio* effective *NN* interactions,[6)] which reproduces the stability of $^{39}$Na as well as the neutron dripline at fluorine and neon. The calculation reveals that the quadrupole deformation plays a key role in nuclear binding in this region and thus in determining the location of the neutron dripline.

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*1 RIKEN Nishina Center
*2 Department of Physics, Tokyo Institute of Technology
*3 Department of Physics, Rikkyo University
*4 Department of Physics, Tohoku University
*5 GSI Helmholtzzentrum für Schwerionenforschung GmbH
*6 National Superconducting Cyclotron Laboratory, Michigan State University

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