Location of the neutron dripline at fluorine and neon[†]

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The location of the neutron dripline has been a long-standing issue, and it is only known up to oxygen (atomic number $Z = 8$) so far. No confirmed extensions of the dripline above $Z = 8$ have been made for nearly 20 years, since ^{24}O (neutron number $N = 16$) was determined to be a dripline nucleus.

In order to investigate the neutron dripline for higher-Z elements such as fluorine ($Z = 9$), neon ($Z = 10$), and sodium ($Z = 11$), we conducted a search for the new isotopes ^{32,33}F, ^{35,36}Ne, and ^{38,39}Na at the RIKEN RIBF. We attempted to observe isotopes beyond the line of the mass number $A = 3Z + 4$, where the most neutron-rich isotopes known so far are located. The search was performed using the projectile fragmentation of an intense ^{48}Ca beam at 345 MeV/nucleon on a 20-mm-thick beryllium target. The projectile fragments were separated and identified in flight by the large-acceptance two-stage fragment separator BigRIPS.[1,2)] The ^{48}Ca-beam intensity was as high as ∼450 particle nA ($\sim 3 \times 10^{12}$ particles/s).

Particle identification was performed at the second stage of the BigRIPS separator, relying on the combination of time of flight (TOF), magnetic rigidity (Bρ), and energy loss (ΔE) measurements, from which the Z and A/Z of the fragments were deduced.[3)] The TOF was measured between two thin plastic scintillators installed at the intermediate and final foci of the second stage. The ΔE was measured using a stack of four identical silicon semiconductor detectors installed at the final focus. The Bρ was determined from a position measurement at the intermediate focus using the same plastic scintillator. The measurement was conducted with two Bρ settings of the BigRIPS separator, the central particle of which was tuned to be ^{33}F and the middle of ^{36}Ne and ^{39}Na, respectively. In these settings, their neighboring isotopes also had a reasonably good transmission.

a)

After extensive running, we observed no events for ^{32,33}F, ^{35,36}Ne, and ^{38}Na and one event for ^{39}Na, implying that these unobserved isotopes were particle unbound. In order to assess the confidence level of the implication, production cross sections were systematically measured as a function of mass number, and the data were compared with the predictions from the EPAX 2.15 systematics[4)] and the Qg systematics.[5)] These systematics allowed us to extrapolate the observed cross sections and, hence, estimate the expected yields of the unobserved isotopes. The comparison of no observed events with the expected yields revealed that the existence of bound ^{32,33}F, ^{35,36}Ne, and ^{38}Na was excluded with high confidence levels. Thus, we concluded that the most neutron-rich and heaviest bound nuclei, corresponding to the dripline nuclei, are ^{31}F and ^{34}Ne for fluorine and neon, respectively. The location of the neutron dripline has thus been extended up to $Z = 10$ for the first time in nearly 20 years, as shown in Fig. 1.

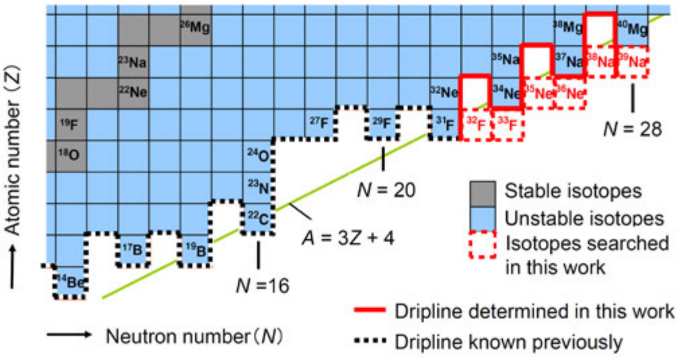

Fig. 1. Section of the nuclear chart showing the location of the neutron dripline determined in the present work.

The location of the neutron dripline is sensitive to the underlying nuclear structure of neutron-rich exotic nuclei, such as the evolution of nuclear shell structure and occurrence of nuclear deformation, which are caused by the characteristic effects of complex nuclear forces.[6–8)] We compared the present results with various nuclear mass and structure models, and we found that no models could consistently account for the nuclear binding of neutron-rich nuclei in the present Z region.

The present results provide new keys to understanding the nuclear stability at extremely neutron-rich conditions and also present a new challenge to nuclear mass models as well as nuclear structure theories and calculations.

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