Discovery of neutron-rich silicon isotopes ^{45,46}Si†

M. Yoshimoto,*1 H. Suzuki,*1 N. Fukuda,*1 H. Takeda,*1 Y. Shimizu,*1 Y. Yanagisawa,*1 H. Sato,*1 K. Kusaka,*1 M. Ohtake,*1 K. Yoshida,*1 and S. Michimasa*1

Determining the limits of nuclear existence is a key objective in nuclear physics. The neutron dripline, which is the boundary beyond which additional neutrons cannot be bound, has only been confirmed up to Ne isotopes. Predictions of the neutron dripline by various theoretical models have not yet converged for elements beyond Ne, which necessitates experimental verification. In this experiment, we investigated the existence of neutron-rich Si isotopes beyond ^{44}Si, whose existence has been confirmed.[1]

The experiment was conducted at the RIKEN radioactive isotope beam factory (RIBF). A primary beam of 345-MeV/nucleon ^{70}Zn was irradiated onto a 10-mm-thick Be target, and the fragments were separated and identified using the BigRIPS separator. The magnetic rigidity ($B\rho$) of the first dipole magnet D1 was set to 6.6988 Tm for optimizing the production of ^{45}Si. A 5-mm-thick Al wedge degrader was placed at the first momentum dispersive focus F1 in the first stage of the BigRIPS to purify the RIs around ^{45}Si. The particle identification (PID) of RIs was performed in the second stage using the TOF-ΔE-$B\rho$ method. Parallel-plate avalanche counters (PPACs), plastic scintillators, and ionization chambers were used for ion trajectory tracking, timing measurements, and energy-deposition measurements, respectively. The PID was achieved by combining the time of flight (TOF), $B\rho$, and ΔE. A 3-mm-thick Al wedge degrader was placed at the momentum dispersive focus F5 in the second stage, which enabled additional atomic number (Z) identification based on the energy loss within the degrader.[2,3] Background events were efficiently removed by analyzing correlations between measured values, such as signal timing and pulse height. Consequently, reliable PID was achieved even for single-event observations.

The obtained PID plot of Z versus mass-to-charge ratio (A/q) is shown in Fig. 1. The events were observed beyond the boundary of known isotopes, indicated by the red line. Six ^{45}Si isotopes were clearly distinguished from other isotopes. One event of ^{46}Si was observed. The probability of misidentifying ^{46}Si as ^{43}Al, the closest isotope, was found to be negligibly small, with a p-value far below 0.01. Therefore, ^{45}Si and ^{46}Si were identified as the new isotopes observed in our study.

The neutron-binding properties of ^{45,46}Si, along with those of ^{49}S and ^{52}Cl, were compared with predictions from major theoretical mass models. The UNEDF0,[4] DRHBc,[5] and VS-IMSRG[6] models successfully reproduced the binding properties of these isotopes; however, the driplines of Si and Ar still differ among these three models. The neutron binding properties of ^{45,46}Si serve as an indicator to predict the neutron dripline of Si isotopes and hold significant implications for the stability of sub-shell closure at $N = 40$ toward Ar isotopes.

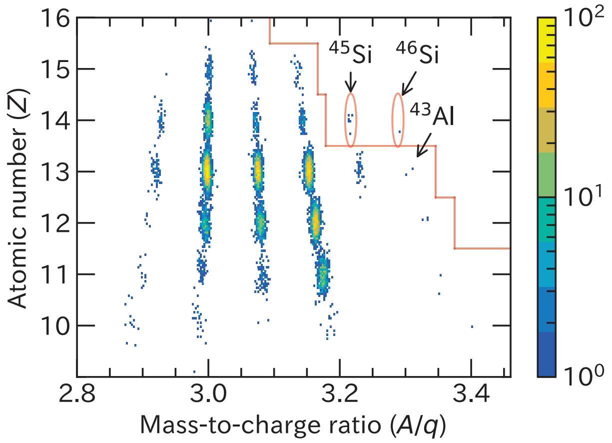

Fig. 1. PID plot of the projectile fragments produced by the in-flight fragmentation reaction of 345 MeV/nucleon ^{70}Zn on a Be target. The red line represents the known isotope limits prior to this work.

References
1) O. B. Tarasov *et al.*, Phys. Rev. C **75**, 064613 (2007).
2) N. Fukuda *et al.*, J. Phys. Soc. Jpn. **87**, 014202 (2018).
3) Y. Shimizu *et al.*, J. Phys. Soc. Jpn. **87**, 014203 (2018).
4) M. Kortelainen *et al.*, Phys. Rev. C **82**, 024313 (2010).
5) P. Gao *et al.*, At. Data Nucl. Data Tables **158**, 101661 (2024).
6) S. R. Stroberg *et al.*, Phys. Rev. Lett. **126**, 022501 (2021).

† Condensed from the article in Prog. Theor. Exp. Phys. **2024**, 101D01 (2024)
*1 RIKEN Nishina Center

DOI:10.34448/RIKEN.APR.58-092