Discovery of ^{60}Ca and Implications For the Stability of ^{70}Ca[†]

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The landscape of atomic nuclei is delineated by the nucleon drip lines beyond which no bound states of lighter or heavier isotopes exist. The location of the neutron drip line provides a key benchmark for nuclear models and the quest to understand the nuclear force. The proton-magic calcium isotopes span the magic neutron numbers 20, 28, 32, 34, and possibly 40 and 50. The calcium chain is just within reach of ab-initio models[1] as well as the broadly applicable mean-field and configuration-interaction models. Observation of ^{59}Ca and ^{60}Ca would test the predictive power of ab-initio models as compared to the energy density functionals (EDFs), and indicate if the success of the ab-initio approaches in describing the masses of the calcium isotopes. Measurements at NSCL[2,3] have demonstrated that the fragmentation of ^{76}Ge and ^{82}Se beams using a two-stage separator can be used to produce new neutron-rich isotopes in the calcium region. We report here the continuation of this work at the RIKEN RIBF facility, using a higher beam energy and intensity, and so accessing the one-order-of-magnitude lower production cross sections needed to explore the stability of ^{59,60}Ca.

The discovery of $^{60}_{20}$Ca$_{40}$ and seven other neutron-rich nuclei near the limits of stability is reported from the projectile fragmentation of 345 MeV/nucleon ^{70}Zn beam with an intensity of 225 particle nA on Be targets at the RI Beam Factory operated by RIKEN Nishina Center and CNS, University of Tokyo. During a 99.5 hour measurement, ^{47}P, ^{49}S, ^{52}Cl, ^{54}Ar, ^{57}K, ^{59,60}Ca, and ^{62}Sc, the most neutron-rich isotopes of the respective elements, were observed for the first time. In addition, one event consistent with ^{59}K was observed. The produced fragments were analyzed and unambiguously identified using the BigRIPS two-stage in-flight separator tuned according to LISE^{++} calculations.[4] Two aluminum wedge-shaped degraders at the F1 and F5 dispersive planes were used at full BigRIPS momentum acceptance to separate and purify the RI beams. The particle identification (PID) was conducted using the ToF-$B\rho$-ΔE-TKE method described in the appendix to the previous work.[5]

The results are compared with the drip-line predictions of a wide variety of mass models. The two isotopes ^{49}S and ^{52}Cl, discovered in this work, emerge as key discriminators between different models. EDFs in best agreement with the limits of existence in the explored region, HFB-22[6] and UNEDF0,[7] predict the even-mass Ca isotopes to be bound out to at least ^{70}Ca (see Fig. 1), at odds with ab-initio models that predict the neutron drip line in Ca to be closer to ^{60}Ca with ^{59}Ca unbound.

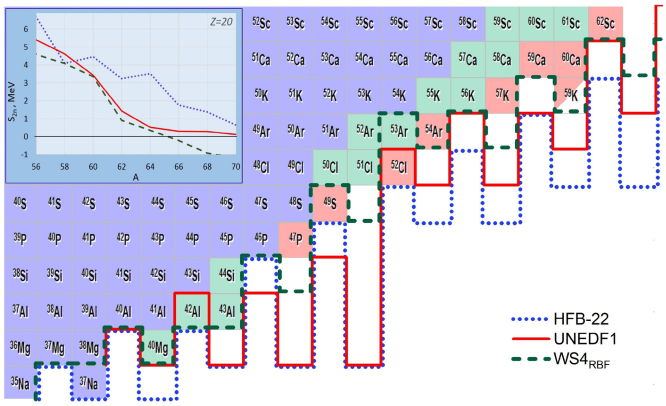

Fig. 1. The region of the chart of nuclides studied in this work. Nuclei highlighted by red background were discovered in this work, green squares denote nuclei discovered at the NSCL since 2007.[2,3,8,9] The neutron drip lines predicted by the HFB-22,[6] UNEDF1,[10] and WS4$_{RBF}$[11] mass models are indicated by the blue dotted, red solid, and green dashed lines, respectively. The model WS4$_{RBF}$ appears to underestimate the bindings of isotopes in this region. HFB-22 and UNEDF1 seem to better predict the drip line. The inset shows the predicted S_{2n} values for even neutron-rich calcium isotopes.

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† Condensed from the article in Phys. Rev. Lett. **121**, 022501 (2018)
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