Study of the $N = 32$ and $N = 34$ shell gap for Ti and V by the first high-precision multireflection time-of-flight mass measurements at BigRIPS-SLOWRI[†]

S. Iimura,[*1,*2,*3,*4] M. Rosenbusch,[*3] A. Takamine,[*1] Y. Tsunoda,[*5] M. Wada,[*3] S. Chen,[*6] D. S. Hou,[*7] W. Xian,[*6] H. Ishiyama,[*1] S. Yan,[*8] P. Schury,[*3] H. Crawford,[*9] P. Doornenbal,[*1] Y. Hirayama,[*3] Y. Ito,[*10] S. Kimura,[*1] T. Koiwai,[*11,*1] T. M. Kojima,[*1] H. Koura,[*10] J. Lee,[*6] J. Liu,[*6,*7] S. Michimasa,[*12] H. Miyatake,[*3] J. Y. Moon,[*13] S. Naimi,[*1] S. Nishimura,[*1] T. Niwase,[*3,*1,*14] A. Odahara,[*2] T. Otsuka,[*11,*1,*10] S. Paschalis,[*15] M. Petri,[*15] N. Shimizu,[*5] T. Sonoda,[*1] D. Suzuki,[*1] Y. X. Watanabe,[*3] K. Wimmer,[*11,*16,*1] and H. Wollnik[*17]

Masses of neutron-rich isotopes with $N \geq 32$ between Ca and Ni have recently been studied intensely as valuable probes of the complex nuclear structure. For Ca isotopes, a pronounced reduction of tensor-interaction effects[1)] due to the decrease of proton valence particles occupying the $\pi f_{7/2}$ orbits has been confirmed by the discovery of two new magic neutron numbers, *i.e.*, $N = 32$ and $N = 34$. In the Ti isotope chain, a shell gap at $N = 32$ had been confirmed, and the collective behavior due to a $\nu g_{9/2}$ level intrusion was found in the region close to $N = 40$ in several studies.[2–4)] As for the $N = 34$ shell gap, previous mass measurements have suggested the existence of a pronounced shell gap with moderate uncertainties.[5,6)] However, a new study has revealed the vanishing of the magicity.

The experiment was performed at RIKEN RI Beam Factory (RIBF), which is operated by an international collaboration team primarily from RIKEN Nishina Center and KEK Wako Nuclear Science Center. Radioactive isotopes (RIs) have been produced by the fragmentation of a 345 MeV/nucleon Zn beam with a Be target and delivered to the ZD MRTOF system[7)] for the first time as part of the SLOWRI project. The new setup has been located downstream of the ZeroDegree spectrometer following the BigRIPS separator.

During the first commission, the masses of 15 neutron-rich nuclei have been measured with high precision and accuracy. Among the results, the mass precisions of ^{55}Sc, ^{56,58}Ti, and $^{56–59}$V have been significantly improved to the order of 10 keV or below. The newly determined masses of ^{58}Ti and ^{59}V were found to deviate from previously measured values, where—especially for ^{58}Ti—an increased binding energy has been measured. Figure 1 shows the newly determined two-neutron shell gap of $N = 34$ isotones (red line) deduced directly from masses. Literature values suggested an enhancement of the gap with Ti and V, whereas there is no gap found in this study, indicating that the $N = 34$ shell gap is a unique feature of Ca.

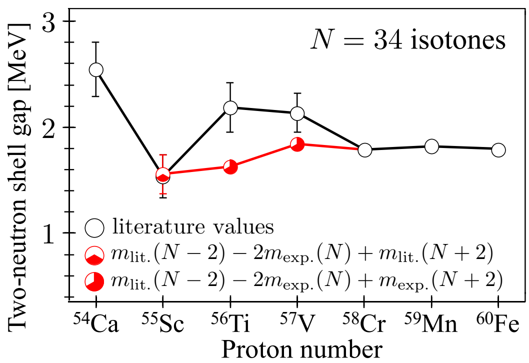

Fig. 1. Two-neutron shell gaps for $N = 34$ isotones including the new mass data. Data are from AME2020 with recent measurements (black open circles) and our experimental values (partly filled red circles).

In order to understand the observed results, we performed new Monte Carlo shell model calculations using the A3DA-m Hamiltonian[8)] and compared the results with conventional shell model calculations, which exclude the higher ($\nu g_{9/2}$, $\nu d_{5/2}$) orbits. The comparison indicates that the reduction of the shell gap in Ti is related to partial occupation of the higher orbitals for the outer two valence neutrons at $N = 34$.

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*1 RIKEN Nishina Center
*2 Department of Physics, Osaka University
*3 Wako Nuclear Science Center (WNSC), IPNS, KEK
*4 Department of Physics, Rikkyo University
*5 Center for Computational Sciences, University of Tsukuba
*6 Department of Physics, University of Hong Kong
*7 Institute of Modern Physics, Chinese Academy of Sciences
*8 IAESPC, Jinan University
*9 Nuclear Structure Group, Lawrence Berkeley National Laboratory
*10 Advanced Science Research Center, Japan Atomic Energy Agency
*11 Department of Physics, University of Tokyo
*12 Center for Nuclear Study, University of Tokyo
*13 Rare Isotope Science Project, Institute for Basic Science
*14 Department of Physics, Kyushu University
*15 School of Physics, University of York
*16 GSI Helmholtzzentrum für Schwerionenforschung GmbH
*17 New Mexico State University