^{78}Ni revealed as a doubly magic stronghold against nuclear deformation[†]

R. Taniuchi,[*1,*2] C. Santamaria,[*3,*2] P. Doornenbal,[*2] A. Obertelli,[*3,*2,*4] and K. Yoneda[*2]
for SEASTAR2014 Collaboration

The doubly magic character of ^{78}Ni was investigated for the first time via the in-beam γ-ray spectroscopic technique at the RIBF. Vital to the experiment was a high intensity ^{238}U primary beam, accelerated by the RIBF's cyclotron complex and followed by the BigRIPS spectrometer[1)] for the production of the secondary cocktail beams. BigRIPS was centered on ^{79}Cu and ^{80}Zn ions, which are bound by one and two protons more than the target isotope ^{78}Ni. Excited states of ^{78}Ni were populated by one- and two-proton knockout reactions, respectively. To produce the excited states in sufficient numbers, a new secondary target system, MINOS,[2)] was implemented. It consisted of a 10-cm long liquid hydrogen target surrounded by a time-projection chamber to trace outgoing protons following the proton knockout reactions. Reaction residues were tagged by the ZeroDegree spectrometer[1)] installed behind MINOS. De-excitation γ rays emitted in prompt coincidence with the secondary reactions were detected by the large volume γ-ray scintillator array DALI2.[3)]

The γ-ray spectra of the $(p, 2p)$ and $(p, 3p)$ reactions are shown in Fig. 1. The energies of the peaks indicated in the figure were deduced by maximum-likelihood fits with simulated response functions. As a result, a clear high-energy γ-ray transition observed at 2,600(33) keV in the $(p, 2p)$ reaction illustrates the persistence of the doubly magic nature of ^{78}Ni. However, another transition at a similar energy, 2,910(43) keV observed in the $(p, 3p)$ channel, questions the stability of the proton and neutron shell closures.

The obtained levels of the excited states have been compared with several state-of-the-art calculations. Two large-scale shell-model calculations, LSSM and MCSM, employing phenomenological interactions well reproduced the experimentally observed transitions just below 3 MeV as two excited 2^+ states feeding the ground state independently. These theoretical predictions interpret the experimental result as ^{78}Ni having two coexisting shapes, spherical in the ground-state band and prolate for the excited band, respectively. Other theoretical approaches, such as the QRPA, Coupled-Cluster, and In-Medium SRG calculations, could solely reproduce the first 2^+ state at 2,600 keV as spherical shape. The absence of the second 2^+ state found at 2,910 keV is understood as due to the limitations of these models such that they do not incorporate the deformed, or collective phenomena. This study suggests that the neutron-rich isotope ^{78}Ni cannot be envisaged as a simple doubly closed-shell nucleus, but rather having a competing deformed structure that prevails for more neutron-rich Ni isotopes and $N = 50$ isotones.

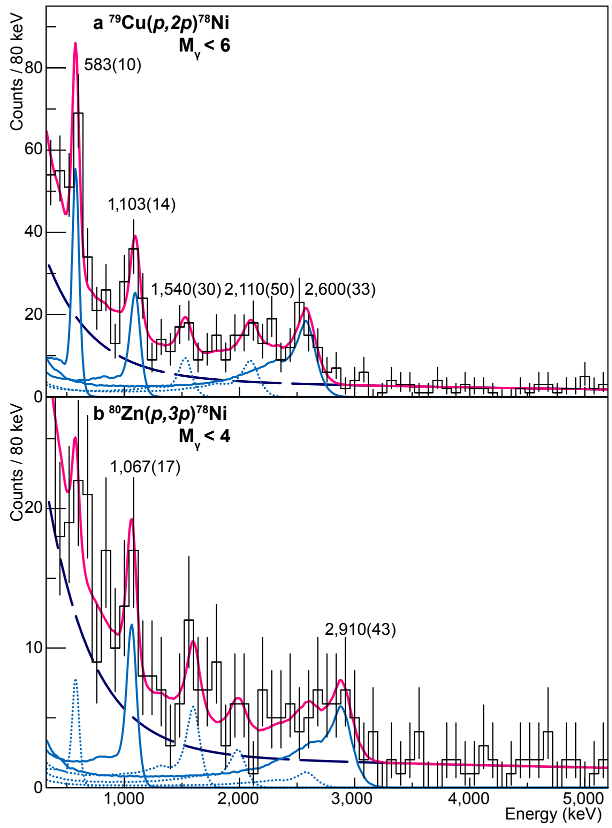

Fig. 1. Doppler-corrected γ-ray spectra of ^{78}Ni for the $(p, 2p)$ and $(p, 3p)$ channels. These histograms are fitted with simulated response functions (light blue lines) and double-exponential background curves (blue dashed line). The labels indicate the energies of the respective peaks. Solid response function lines had significance levels above 3σ, while the dotted ones did not. The magenta line in each panel shows the summed curve of the simulated functions.

References

1) T. Kubo *et al.*, Prog. Theor. Exp. Phys. **2012**, 3C003 (2012).
2) A. Obertelli *et al.*, Eur. Phys. J. A **50**, 8 (2014).
3) S. Takeuchi *et al.*, Nucl. Instrum. Methods Phys. Res. A **763**, 596 (2014).

† Condensed from the article in Nature **569**, 53–58 (2019)

*1 Department of Physics, The University of Tokyo
*2 RIKEN Nishina Center
*3 IRFU, CEA, Université Paris-Saclay
*4 Institut für Kernphysik, Technische Universität Darmstadt