Rotational level structure of sodium isotopes inside the "Island of Inversion" †

P. Doornenbal,[*1] H. Scheit,[*1,*2] S. Takeuchi,[*1] Y. Utsuno,[*3] N. Aoi,[*1] K. Li,[*1,2] M. Matsushita,[*1,*4] D. Steppenbeck,[*1] H. Wang,[*1,*2] H. Baba,[*1] E. Ideguchi,[*5] N. Kobayashi,[*6] Y. Kondo,[*6] J. Lee,[*1] S. Michimasa,[*5] T. Motobayashi,[*1] T. Otsuka,[*5] H. Sakurai,[*1] M. Takechi,[*1] Y. Togano,[*1] and K. Yoneda[*1]

The study of neutron-rich Ne, Na, and Mg nuclei around the breakdown of the $N = 20$ neutron magic number, an area in the Segré chart termed "Island of Inversion"[1)] has provided a wealth of information on the evolution of nuclear shell structure away from the valley of β stability. Due to its location in the proximity of the neutron drip-line, accessing the "Island of Inversion" is an experimental challenge. In this paper, we report on the first γ-ray spectroscopy performed for the $N = 23, 24$ sodium isotopes ^{34,35}Na and a new transition in ^{33}Na. For the latter nucleus, previous measurements suggested that the observed two transitions originate from a $7/2^+_1 \rightarrow 5/2^+_1 \rightarrow 3/2^+_{g.s.}$ cascade and the energy ratio was found to be close to an ideal $K = 3/2$ rotational band in the strong coupling limit[2)].

A ^{48}Ca beam with an average intensity of 70 particle nA was accelerated by the Superconducting Ring Cyclotron to 345 MeV/u and incident on a 15 mm thick beryllium production target. A combination of two magnetic dipoles and a 15 mm thick aluminum degrader was utilized to filter a ^{36}Mg secondary beam with the BigRIPS fragment separator[3)] by applying the $B\rho - \Delta E - B\rho$ method. For further purification, a second aluminum degrader of 5 mm thickness was inserted at the dispersive focal point of the second BigRIPS stage. After passing BigRIPS, the secondary beams were incident on 2.54 g/cm^2 carbon and 2.13 g/cm^2 CH_2 (polyethylene) reaction targets, respectively. BigRIPS was operated with its full momentum acceptance of ±3% and the average intensity of ^{36}Mg was 90 particles per second. Gamma-rays emitted in coincidence with the secondary reactions were detected with the DALI2 array[4)], which was composed of 186 large-volume NaI(Tl) detectors. The secondary reaction products were identified with the ZeroDegree Spectrometer[3)].

In the present work, a third γ-ray transition was observed for ^{33}Na at 760(13) keV in addition to the two known ones, and forms a doublet with the $7/2^+_1 \rightarrow 5/2^+_1$ decay. For the odd-odd nucleus ^{34}Na, a single γ-ray transition was observed at 451(7) keV, while the energy spectrum of ^{35}Na exhibited transitions at 373(5) and 641(16) keV. The level structure of the odd-even sodium isotopes was found to be well described by the SDPF-M effective interaction[5)].

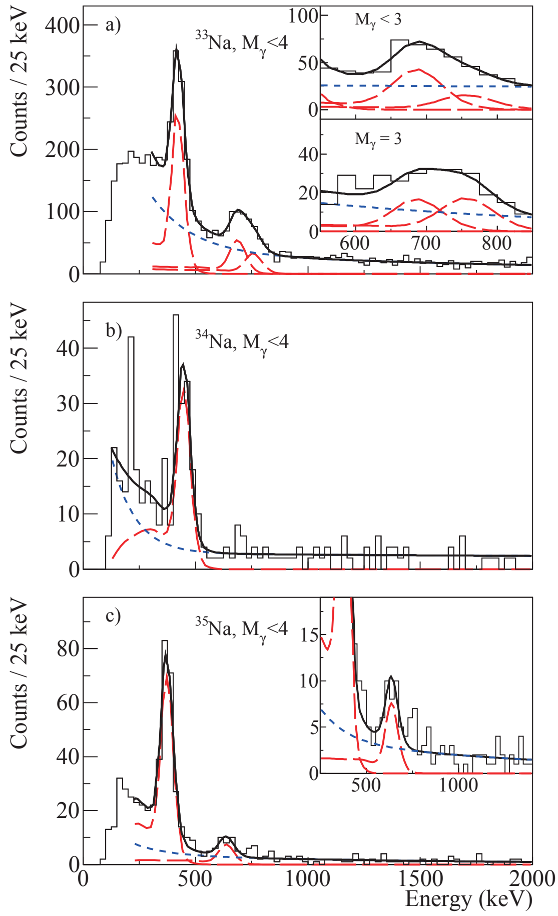

Fig. 1. Doppler corrected γ-ray spectra in coincidence with ^{33}Na a), ^{34}Na b), and ^{35}Na c). The analysis was restricted to event with aγ-ray multiplicity M_γ of less than 4.

† Condensed from the article in Prog. Theor. Exp. Phys. 2014, 053D01 (2014).

*1 RIKEN Nishina Center
*2 State Key Laboratory of Nuclear Physics and Technology, Peking University
*3 Advanced Science Research Center, Japan Atomic Energy Agency
*4 Department of Physics, Rikkyo University
*5 Center for Nuclear Study, University of Tokyo
*6 Department of Physics, Tokyo Institute of Technology

References

1) E. K. Warburton *et al.*, Phys. Rev. C 41, 1147 (1990).
2) A. Gade *et al.*, Phys. Rev. C 83, 044305 (2011).
3) T. Kubo *et al.*, Prog. Theor. Exp. Phys. 2012, 03C003 (2012).
4) S. Takeuchi *et al.*, Nucl. Instr. Meth. A 763, 596 (2014).
5) Y. Utsuno *et al.*, Phys. Rev. C 60, 054315 (1999).