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Intermediate-energy Coulomb excitation of the neutron-rich Ge isotopes around N = 50

H. Iwasaki[1,a], N. Aoi[2], S. Takeuchi[2], S. Ota[3], H. Sakurai[1], M. Tamaki[4], T.K. Onishi[1], E. Takeshita[5], H.J. Ong[1], N. Iwasa[6], H. Baba[5], Z. Elekes[2], T. Fukuchi[4], Y. Ichikawa[1], M. Ishihara[2], S. Kanno[5], R. Kanungo[2], S. Kawai[5], T. Kubo[2], K. Kurita[5], S. Michimasa[4], M. Niikura[4], A. Saito[5], Y. Satou[7], S. Shimoura[4], H. Suzuki[1], M.K. Suzuki[1], Y. Togano[5], Y. Yanagisawa[2], and T. Motobayashi[2]

[1] Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan
[2] RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
[3] Department of Physics, Kyoto University, Kitashirakawa, Kyoto 606-8502, Japan
[4] Center for Nuclear Study (CNS), University of Tokyo, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
[5] Department of Physics, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima, Tokyo 171-8501, Japan
[6] Department of Physics, Tohoku University, Aoba, Sendai, Miyagi 980-8578, Japan
[7] Department of Physics, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8551, Japan

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Abstract. Structure of the neutron-rich Ge isotopes at and around $N = 50$ has been investigated via intermediate-energy Coulomb excitation using secondary beams of $^{78-82}$Ge incident on a Pb target. The $B(E2)$ values for the low-lying 2^+ states have been extracted and compared with the data for neighboring isotopes around $N = 50$. In addition, a new method of intermediate-energy two-step Coulomb excitation has been proposed as a spectroscopic tool to study the 4^+ states in neutron-rich even-even nuclei. The first application of the method and its results are presented.

PACS. 23.20.Js Multipole matrix elements – 25.70.De Coulomb excitation – 27.50.+e 59≤ A ≤89

1 Introduction

Neutron-rich nuclei in the vicinity of the doubly magic nucleus ^{78}Ni afford one of the best opportunities to investigate the evolution of nuclear structure toward the drip lines. We have recently performed in-beam γ studies of the neutron-rich isotopes $^{78-82}$Ge around $N = 50$ by means of intermediate-energy Coulomb excitation. Among the various reactions employed in γ-spectroscopic studies with intermediate-energy radioactive-ion (RI) beams [1,2,3,4,5], Coulomb excitation provides a unique means to determine both energies and transition probabilities $B(E2)$ for the low-lying 2^+ states. The aim of the present work is to investigate such $E2$ properties of the neutron-rich Ge isotopes, which enables us to depict systematic trends of the collective behavior toward the neutron magic number $N = 50$. In addition, a new method of intermediate-energy two-step Coulomb excitation has been applied for the first time to examine a possible access to higher excited states.

[a] Conference presenter;
e-mail: hiwasaki@phys.s.u-tokyo.ac.jp

2 Experiment

The experiment was performed at the RIPS facility in RIKEN. The secondary beams of the Ge isotopes were produced by fragmentation of a 63 AMeV ^{86}Kr beam on a 66.2-mg/cm^2-thick ^{9}Be target. A maximum intensity of around 100 pnA was achieved for the primary ^{86}Kr beam, owing to the recently developed acceleration scheme of the RIKEN Ring Cyclotron with the RFQ+RILAC+CSM injection system [6]. The event-by-event measurement of magnetic rigidity ($B\rho$), time-of-flight, and energy loss (ΔE) information allowed a clear isotopic identification of the incident beams. The secondary-beam intensities were around 6 kcps for ^{76}Ge, 2 kcps for ^{78}Ge, 1 kcps for ^{80}Ge, and 100 cps for ^{82}Ge in the separate $B\rho$ settings optimized for each isotope. The secondary beams were transported to the experimental area, where a Pb target was set to excite the projectiles.

Scattered particles were detected and identified by an array of a Si telescope and a NaI(Tl) calorimeter [7], which provided energy-loss (ΔE) and E information, respectively. The Si telescope consisted of 16 silicon detectors, while the NaI(Tl) calorimeter comprised 132 NaI(Tl) crystals.

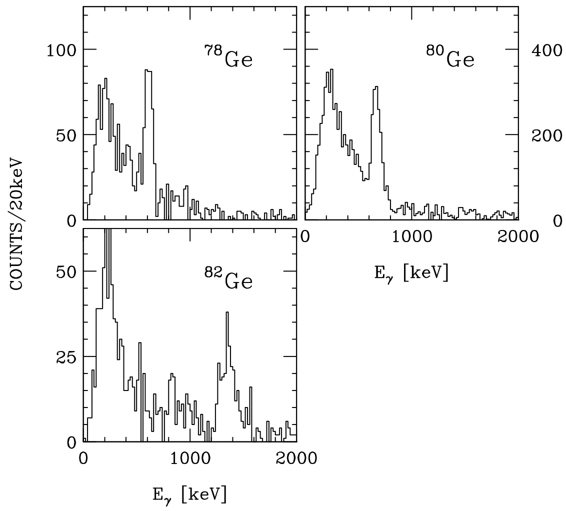

Fig. 1. Doppler-shift corrected γ-ray energy spectra following the ^{78,80,82}Ge + Pb reactions.

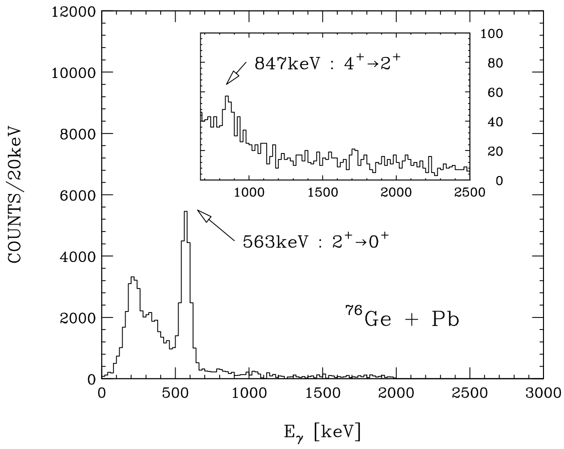

Fig. 2. Doppler-shift corrected γ-ray energy spectra obtained in the ^{76}Ge + Pb scattering. The inset shows the spectrum gated on the 563 keV transition in ^{76}Ge.

De-excitation γ-rays were measured in coincidence with the scattered particles by the DALI2 array [8], which is composed of 158 NaI(Tl) scintillators. Typical γ-ray energy spectra measured in coincidence with the even-even Ge isotopes are shown in fig. 1.

3 Intermediate-energy Coulomb excitation of $^{78-82}$Ge

As shown in fig. 1, the γ-ray peaks corresponding to the $2^+ \to 0^+$ transitions are clearly seen for ^{78,80,82}Ge (620 keV for ^{78}Ge, 660 keV for ^{80}Ge, and 1350 keV for ^{82}Ge). From the yields of the peaks, one can extract the Coulomb excitation cross-sections and hence the reduced transition probabilities $B(E2)$. Preliminary analysis suggests the $B(E2)$ values of around 0.2 e^{2}b^2 for ^{78}Ge and 0.1 e^{2}b^2 for ^{80,82}Ge. The systematic trends of $B(E2)$ for the Ge isotopes with $N = 46$–50 are very similar to the Kr isotopes with $N = 46$–50 [9] (0.223(10) e^{2}b^2 for ^{82}Kr, 0.125(6) e^{2}b^2 for ^{84}Kr, and 0.122(10) e^{2}b^2 for ^{86}Kr), suggesting a picture that $N = 50$ is still magic in the neutron-rich Ge isotopes.

The reliability of our measurements of $B(E2)$ has been checked by comparing the present results on stable nuclei with adopted values determined from several measurements of low-energy Coulomb excitation [9]. Good agreement between the present $B(E2)$ results of 0.25(3) e^{2}b^2 for ^{80}Se and 0.17(3) e^{2}b^2 for ^{82}Se and the adopted values of 0.253(6) e^{2}b^2 for ^{80}Se and 0.184(5) e^{2}b^2 for ^{82}Se supports the validity of the method of the intermediate-energy Coulomb excitation.

4 Intermediate-energy two-step Coulomb excitation

To develop a new method for the investigation of higher excited states in neutron-rich nuclei, we have performed a measurement of intermediate-energy two-step Coulomb excitation. So far, no significant transition associated with two-step excitation has been observed in Coulomb excitation studies with intermediate-energy RI beams of $Z \simeq 10$–20 nuclei [1,4,5]. However, for heavier nuclei with $Z \geq 30$, one may expect a large two-step excitation cross-section even at intermediate incident energies, since Coulomb excitation cross-section sharply rises with increasing Z.

Figure 2 shows the experimental results of the two-step excitation applied for the secondary beam of ^{76}Ge at 37 AMeV. A γ-ray peak associated with the $2^+ \to 0^+$ transition (563 keV) in ^{76}Ge is evident. In the γ-γ coincidence spectrum gated on the 563 keV transition, the γ-ray peak corresponding to the $4^+ \to 2^+$ transition is also observed at around 850 keV. The $B(E2)$ values for the observed transitions were obtained from the γ-ray peaks, and found to be in fairly good agreement with the previously known values. These observations thus demonstrate the usefulness of the present method for a simultaneous determination of the excitation energies of the 2^+ and 4^+ states as well as the $B(E2)$ values for the $0^+ \to 2^+$ and $2^+ \to 4^+$ transitions in neutron-rich even-even nuclei.

5 Summary

We have studied intermediate-energy Coulomb excitation of the neutron-rich Ge isotopes around $N = 50$. The present measurement completes the systematic data of $B(E2)$ for the Ge isotopes up to $N = 50$. We have also showed that intermediate-energy Coulomb excitation provides a useful spectroscopic tool to investigate the low-lying 2^+ and 4^+ states of neutron-rich nuclei.

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