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RAPID COMMUNICATIONS

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$(\nu g_{9/2}^{-2})_{8^+}$ isomers in $^{82}Se_{48}$ and $^{80}Ge_{48}$ populated by deep-inelastic collisions

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New 8^+ isomers in ^{82}Se and ^{80}Ge and their decays were studied by observing γ rays from the projectilelike fragments produced by the deep-inelastic collision ^{198}Pt+743 MeV ^{82}Se. The lifetimes of the 8^+ isomers have been measured to be $T_{1/2}=6.6(4)$ ns and $T_{1/2}>0.4$ ns for ^{82}Se and ^{80}Ge, respectively. The $N=48$ isotones from $^{80}_{32}$Ge to $^{94}_{46}$Pd turned out to show quite different energy spectra of the yrast states up to $I^\pi=8^+$, depending on the orbital occupied by valence protons. [S0556-2813(99)50105-2]

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From a theoretical point of view, the yrast states up to $I^\pi=8^+$ in $N=48$ isotones can be ascribed to the two-hole states $\nu g_{9/2}^{-2}$ for the $N=50$ closed shell. Furthermore, their 8^+ yrast states are very likely to become isomers. Indeed, such isomers have been observed in the isotones from $^{84}_{36}$Kr$_{48}$ to $^{94}_{46}$Pd$_{48}$ [1–3]. These nuclei except ^{84}Kr show similar energy spectra up to the 8^+ states, which suggests that the $(\nu g_{9/2}^{-2})_{I^\pi=0^+,2^+,4^+,6^+,8^+}$ configurations dominate the yrast states. However, ^{84}Kr has a large energy gap of over 1 MeV between the 6^+ and 4^+ states. For ^{82}Se and ^{80}Ge, the yrast states over $I^\pi=4^+$ have not yet been identified. The excited states of these nuclei are hardly populated by fusion reactions, and have been studied through β decay [1,4] or nucleon transfer reaction [1]. In this Rapid Communication, we report on a search for the isomers in ^{82}Se and ^{80}Ge using deep-inelastic collisions by means of an isomer-scope [5].

An experiment was carried out at the tandem booster facility of the Japan Atomic Energy Research Institute [6]. A ^{198}Pt target, 96% enriched and 4.3 mg/cm^2 thick, was bombarded with 743 MeV ^{82}Se nuclei. With the isomer-scope, we measured the γ rays from isomers of the projectilelike fragments (PLF's) produced by deep-inelastic collisions (DIC's). An annular type of Si detector was placed 5.5 cm downstream from the target to catch the PLF's. It was divided into four sections to cover the scattering angles from 15° to 35° by 5° steps. Five Ge detectors with 30% efficiency were set at the periphery of the Si detector to detect γ rays from PLF's stopped in the Si detector. Energy and timing signals from the PLF's and γ rays were registered event by event on magnetic tape. Details of the isomer-scope and the method of analyzing the data were previously described elsewhere [5,7,8].

The nucleus ^{82}Se had a rich isomer yield. The 373.5(3) and 1409.9(3) keV γ rays were found to be coincident with

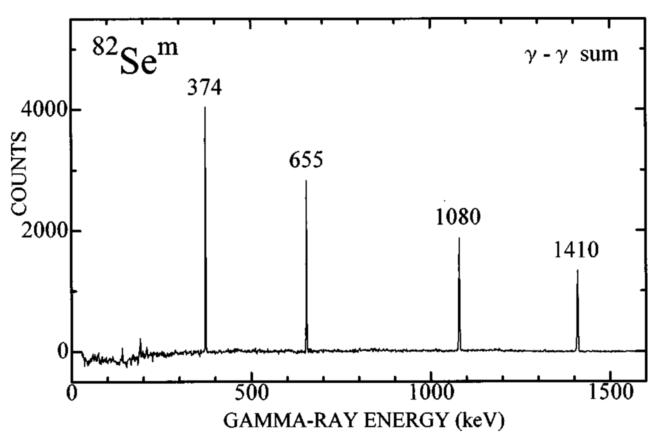

FIG. 1. A mutual coincidence spectrum of γ rays from the new ^{82}Se isomer. The gates for sorting the event records were set on the 374, 655, 1080, and 1410 keV γ rays.

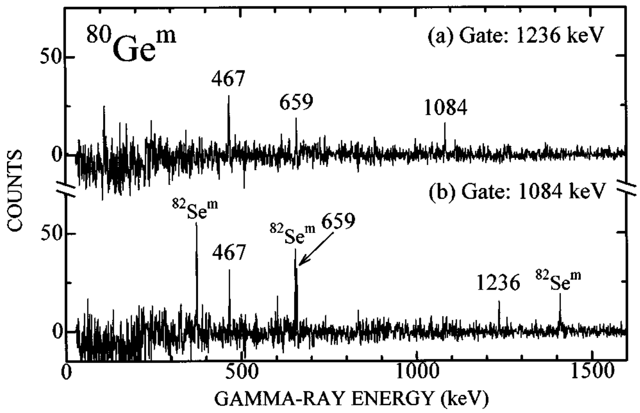

FIG. 2. Coincidence spectra of γ rays from the ^{80}Ge isomer. The gates were set on the γ rays with energies of (a) 1236 and (b) 1084 keV.

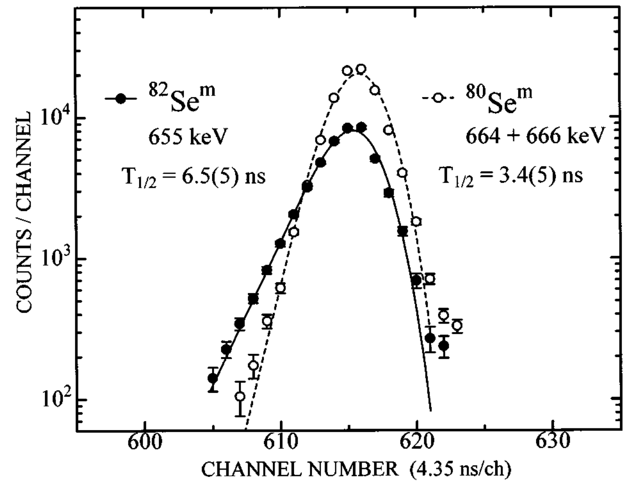

FIG. 3. Time spectra of γ rays from ^{82}Se^m and ^{80}Se^m. These were obtained from $t_{\gamma-\mathrm{PLF}}$ coincidence data. The experimental data were fitted into a convolution curve, assuming a Gaussian shape for the prompt time distribution.

the known 1080.4($4^+ \to 2^+$) and 654.8($2^+ \to 0^+$) keV γ rays [1]. These four transitions were coincident with each other; a $\gamma\gamma$-coincidence sum spectrum for these transitions is shown in Fig. 1. The ^{82}Se^m nuclei emitting these γ rays were strongly scattered at angles 25°–30° but were hardly detected at the inner angles of 15°–20°. At angles 25°–30°, the PLF energy spectrum of ^{82}Se^m peaked at 566 MeV, while elastically scattered ^{82}Se nuclei had a mean energy of 613 MeV. Thus, the ^{82}Se^m nuclei were produced via the DIC with a dissipation energy of about 50 MeV.

The yield of ^{80}Ge^m was about one twentieth that of ^{82}Se^m. A ^{80}Ge isomer was found by sorting out γ rays in coincidence with the known 1083.7($4^+ \to 2^+$) and 659.2($2^+ \to 0^+$) keV γ rays [1,4]. The 466.8(3) and 1236.0(4) keV γ rays were coincident with these gate γ rays. Furthermore, these four transitions were coincident with each other; $\gamma\gamma$-coincidence spectra for two gate γ rays are shown in Fig. 2. These four transitions were previously observed by β decay of ^{80}Ga [4], but for the levels above the 4^+ state, no information has been obtained about spins and parities.

The lifetimes of the isomers in ^{82}Se and ^{80}Ge were as short as a few ns. For ^{82}Se^m, the lifetime was determined from the $t_{\gamma-\mathrm{PLF}}$ time spectra. Figure 3 shows the time spectrum for the 655 keV γ ray in ^{82}Se. The time spectrum for a shorter-life isomer in ^{80}Se is also shown in the same figure, which represents the time resolution well enough to deduce the lifetime of ^{82}Se^m; the isomer in ^{80}Se was found in the present experiment to decay via a γ-ray cascade of 419-664-1035-666 keV. The half-lives shown in Fig. 3 were obtained by the convolution of the prompt time distribution of a Gaussian shape. The half-lives for the four γ rays decaying from ^{82}Se^m were also evaluated by a slope method. These analyses gave the same half-lives within experimental errors, and thus we adopted the value of $T_{1/2}=6.6(4)$ns for the isomer in ^{82}Se.

For ^{80}Ge^m, it was difficult to extract the lifetime from the $t_{\gamma-\mathrm{PLF}}$ time spectra because of their poor statistics. Instead of this analysis, a lower bound of the lifetime was estimated from the γ-ray yields. In the isomer-scope, PLF's travel a distance of 6.2 cm, i.e., take a flight of about 1.7 ns before they reach the Si detector. Thus, an isomer with a much shorter lifetime than this flight time decays in flight. In the present experiment, the γ-ray yields of the $N=48$ isotones ^{84}Kr^m ($T_{1/2}=1.84$ μs), ^{82}Se^m, and ^{80}Ge^m were measured to be ^{84}Kr^m:^{82}Se^m:^{80}Ge$^m = 1{:}1.6(1){:}0.07(1)$. Taking account of the neutron excess of ^{80}Ge^m, this ratio seems reasonable and suggests ^{80}Ge^m would not decay as much in flight. To estimate the lower bound of the lifetime, we took a conservative assumption that the ^{80}Ge^m yields at most the same as ^{84}Kr^m in the reaction employed. This assumption gives an attenuation in flight, $\exp(-1.7/\tau)$, larger than 0.07, resulting in $T_{1/2}>0.4$ ns.

The decay schemes of ^{82}Se^m and ^{80}Ge^m are shown in Fig. 4 together with those of the known 8^+ isomers in the $N=48$ isotones. The new 374 and 1410 keV γ rays in ^{82}Se, and the 467 and 1236 keV γ rays in ^{80}Ge, were assigned to the $8^+ \to 6^+ \to 4^+$ transitions, assuming the stretched $E2$ coupling scheme for the yrast states. This assumption is based on the property that DIC's bring large angular momenta to the fragment nuclei and populate yrast or near yrast states in these nuclei. The lifetime data also support the above assignments; the 374 and 467 keV γ rays are isomeric $E2$ transitions.

In ^{80}Ge, as mentioned before, the 467 and 1236 keV γ rays were also measured through the β decay of ^{80}Ga by Hoff and Fogelberg [4]. Our 8^+ assignment to ^{80}Ge^m suggests the existence of a high-spin, e.g., 7^-, β-decaying isomer in ^{80}Ga. This suggestion, however, contradicts their result [4] that no β-decaying isomer exists in ^{80}Ga. They reached this conclusion by comparing the γ-ray intensities of ^{80}Ge populated by ^{80}Zn(0^+)$\to$^{80}Ga$\to$^{80}Ge with those populated by ^{80}Ga$\to$^{80}Ge. However, as they mentioned, the production yield of ^{80}Zn was very small in their experiment. Therefore, their experiment could not exclude the possible existence of a high-spin β-decaying isomer with a cross section lower than their experimental limit.

As shown in Fig. 4, ^{86}Sr, ^{88}Zr, ^{90}Mo, and ^{92}Ru have 8^+ states at almost the same excitation energy; in ^{94}Pd [3], the 8^+ and 6^+ states are excited at somewhat lower energies. They show a trend that the excitation energies of the 2^+ and 4^+ states decrease monotonically as the atomic number in-

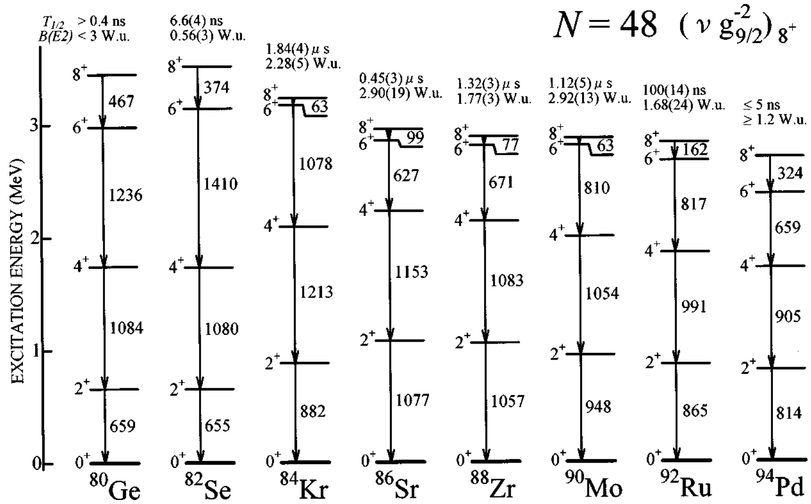

FIG. 4. Decay schemes of the 8^+ isomers in the $N=48$ isotones from $^{80}_{32}Ge$ to $^{94}_{46}Pd$. Transition energies are given in units of keV. The $B(E2;8^+\rightarrow6^+)$ values are also shown.

creases. Compared with these nuclei, ^{84}Kr has a large energy gap of over 1 MeV between the 6^+ and 4^+ states. In ^{82}Se and ^{80}Ge, the 8^+ states are excited at higher energies, the 6^+ states lying about 400 keV below them. The energy gap between the 6^+ and 4^+ levels further increases while the 2^+ and 4^+ levels lie lower in energy than in ^{84}Kr. The energy spectra of ^{82}Se and ^{80}Ge are rather similar to the collective bands backbending at the 8^+ state. In summary, the energy spectra of the $N=48$ isotones with $Z<38$ differ significantly from those with $Z\geqslant38$. This difference probably originates from the orbital occupied by valence protons; in the former nuclei the valence protons mainly occupy the fp orbitals while in the latter they occupy the $g_{9/2}$ orbital.

The $B(E2)$ values for the $8^+\rightarrow6^+$ transitions in the $N=48$ isotones are also given in Fig. 4. These values are not far from the Weisskopf estimates and seem not to be as systematic as the energy levels shown above. For $^{82}Se^m$, however, the $B(E2)$ value of 0.56(3) W.u. is significantly smaller than those in heavier isotones. This fact suggests that the configuration of the 8^+ state is different from that of the 6^+ state in ^{82}Se; the former state mainly comprises the $(\nu g_{9/2}^{-2})_{8^+}$ component while in the latter state, other components mix largely with $(\nu g_{9/2}^{-2})_{6^+}$. This interpretation is in good accord with the energy spectrum in ^{82}Se.

In conclusion, we have found the 8^+ isomers in ^{82}Se and ^{80}Ge. The yrast states up to $I^\pi=8^+$ in the $N=48$ even isotones show quite different energy spectra, depending on whether valence protons occupy the fp or $g_{9/2}$ orbital.

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[1] R. B. Firestone and V. S. Shirley, *Table of Isotopes*, 8th ed. (Wiley, New York, 1996).

[2] E. Nolte, G. Korschinek, and U. Heim, Z. Phys. A **298**, 191 (1980).

[3] M. Gorska, H. Grawe, D. Foltescu, D.B. Fossan, R. Grzywacz, J. Heese, K.H. Maier, M. Rejmund, H. Roth, R. Schubart, Ö. Skeppstedt, and K. Spohr, Z. Phys. A **353**, 233 (1995).

[4] P. Hoff and B. Fogelberg, Nucl. Phys. **A368**, 210 (1981).

[5] T. Ishii, M. Itoh, M. Ishii, A. Makishima, M. Ogawa, I. Hossain, T. Hayakawa, and T. Kohno, Nucl. Instrum. Methods Phys. Res. A **395**, 210 (1997).

[6] S. Takeuchi, T. Ishii, M. Matsuda, Y. Zhang, and T. Yoshida, Nucl. Instrum. Methods Phys. Res. A **382**, 153 (1996).

[7] I. Hossain, T. Ishii, A. Makishima, M. Asai, S. Ichikawa, M. Itoh, M. Ishii, P. Kleinheinz, and M. Ogawa, Phys. Rev. C **58**, 1318 (1998).

[8] T. Ishii, M. Asai, I. Hossain, P. Kleinheinz, M. Ogawa, A. Makishima, S. Ichikawa, M. Itoh, M. Ishii, and J. Blomqvist, Phys. Rev. Lett. **81**, 4100 (1998).