Nuclear g-Factor and Halflife of the 2395 keV Isomer in 217Ra

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The nuclear structure of ^{217}Ra has been studied by Sugawara et al.[1] and Roy et al.[2] using the in-beam spectroscopy method. Low-lying levels in ^{217}Ra are explained by a system of the ^{214}Ra core and three neutrons, and experimental levels are classified into three kinds of states with configurations of $[(\pi h_{9/2}{}^6)_{0^+} \otimes (\nu g_{9/2}{}^3)]_{9/2-21/2^+}$, $[(\pi h_{9/2}{}^6)_0 \otimes (\nu g_{9/2}{}^2 i_{11/2})]_{11/2-27/2^+}$ and $[(\pi h_{9/2}{}^6)_{0^+} \otimes (\nu g_{9/2}{}^2 j_{15/2})]_{15/2-31/2^-}$.[1,2] The lowest 29/2$^+$ level at 2303 keV is considered as $[(\pi h_{9/2}{}^6)_{0^+} \otimes (\nu g_{9/2} i_{11/2}{}^2)]_{29/2^+}$ configuration. The J = 33/2$^+$ isomer at 2395 keV is proposed as a state of ($g_{9/2}\, i_{11/2}{}^2$) neutrons coupled to the 2$^+$ core-excited state of ^{214}Ra[2,3]: $[(\pi h_{9/2}{}^6)_{2^+} \otimes (\nu g_{9/2} i_{11/2}{}^2)]_{33/2^+}$. The energy difference between the 29/2$^+$ and 33/2$^+$ states is however considerably smaller than the energy of the first 2$^+$ state in ^{214}Ra. Figure 1 shows a level scheme of ^{217}Ra reported by Sugawara.[3]

The purpose of the present work is to investigate the configuration of the isomer by the nuclear g-factor. The levels in ^{217}Ra were populated by the ^{208}Pb(^{12}C,3n)^{217}Ra reaction using $^{12}C^{4+}$ beams of 67 and 70 MeV from the CYRIC cyclotron. The metallic ^{208}Pb target 98.9% enriched, of 16.0 mg/cm^2 thickness, was placed in the center of the pole gap of an electromagnet. The g-factor was measured using the time integral perturbed angular distribution (TIPAD) method of in-beam γ-rays. Since the intensity of γ-ray in the 92 keV isomeric transition is very weak due to high internal conversion coefficient, we measured the TIPADs for the 229 keV γ-ray: one of the cascade members from the isomer.

The TIPADs of the 229 keV γ-ray were measured for 6 angles at E(^{12}C) = 67 MeV and for 5 angles at 70 MeV from 60° to 130° with germanium detectors. Effective magnetic fields of B = ±2.001 T were applied on the target perpendicularly to the beam detector plane. Deflection of the beam by the magnetic field was corrected with a magnetic channels system, so that the beam-angle at the center of the target was reduced to be within ±0.2°.

Since the 229 keV transition is not isomeric, the observed 229 keV γ-rays have a prompt component arisen from side feedings. Observed angular shift Δ in the TIPAD by the Larmor precession is therefore smaller than the shift δ for the γ-ray with the prompt and delayed components is given as

$$W(\theta) = \alpha(b_0 + \sum_n b_n \cos(n\theta)$$

$$+ \beta\{b'_0 + \sum_n \frac{b'_n}{\sqrt{1+n^2\omega^2\tau^2}} \cos(n(\theta-\delta))\},$$

$$\alpha + \beta = 1,$$

and $$\delta = (1/n)\tan^{-1}(n\omega\tau),$$

where α and β are intensities of the prompt and delayed components respectively and δ is the mean rotation angle for the isomer having the meanlife τ by the Larmor precession with a frequency ω. In the above expression we neglected any perturbation for other states except the isomer.

Figure 2 shows an experimental result of the TIPADs measured at $E(^{12}C)$ = 67 MeV. Two experimental angular distributions for the fields of upward and downward directions were simultaneously fitted to the expression:

$$W(\theta, \pm\Delta) = B_0 + \Sigma B_n \cos(n(\theta \mp \Delta + \phi)),$$

where ϕ is deviation from the 90° symmetry in the experimental arrangement. For the small value of δ we obtain a simple relation:

$$\Delta = \beta\delta.$$

We measured also time distributions of the 229 keV γ-ray in order to obtain α, β and τ in two parameter (E_γ - $t_{rf,\gamma}$) list mode. The data were first converted into energy spectra for time gates with a proper width taken into account the statistics in the division of the TAC range, then intensities of the 229 keV peaks were calculated by the program SAMPO and a background subtracted time spectrum is obtained from these intensities after normalization for the time width. An example of the time spectrum measured at 67 MeV is shown in Fig. 3. We analyzed these time distributions by the convolution method assuming the time response function with a shape of Gaussian plus exponential tails.

The experimental results are summarized in Table 1. The nuclear g-factor is deduced from the relation:

$$g = \omega\hbar/\mu_N B,$$

where μ_N is the nuclear magneton. Values of the g-factor were to be −0.041(81) and −0.091(59) for the 67 and 70 MeV experiments respectively. We obtained the halflife and g-factor of the isomer:

$$T_{1/2} = 3.88 \pm 0.10 \text{ ns}$$
$$\text{and} \quad g = -0.074 \pm 0.048$$

as the final results from the weighted mean of the two measurements. The present result of lifetime is somewhat smaller than the value 5.0 ns of Roy et al.[2)]

The experimental g-factor was compared with calculated values for possible configurations with the spin and parity of $33/2^+$. The configurations and corresponding g-factors are listed in Table 2. The g-factors were calculated by the additivity relation using values of g-factors for states listed in Table 3, which were taken from experimental and theoretical results for the states in neighbouring nuclei. We propose a configuration of the isomer as the most probable one:

$$((2^+(\text{in } ^{214}\text{Ra}) \otimes \nu g9/2(i_{11/2}{}^2))_{33/2+} \text{ of } 51\%) + ((\nu g_{9/2}(j_{11/2}{}^2))_{33/2+} \text{ of } 49\%).$$

The intensities of the two components include errors of 20%. Although Roy et al. has proposed the configuration which consists of the first term only as mentioned above, the present result can not be explained by that only and demands an admixture of the $\nu g_{9/2}(j_{11/2}{}^2)$ component.

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Table 1. Experimental Results on the TIPADs and Time Distributions.

TIPAD					TIME DISTRIBUTION	
E (MeV)	A_2	A_4	Δ (deg)	δ (deg)	$\beta/(\alpha+\beta)$	τ (ns)
67	0.23(21)	−0.22(15)	0.67(131)	1.24(247)	0.538(11)	5.57(16)
70	0.26(23)	−0.18(16)	1.92(121)	2.89(188)	0.665(72)	5.77(37)

Table 2. Various configurations with J = 33/2+ and values of calculated g-factors.

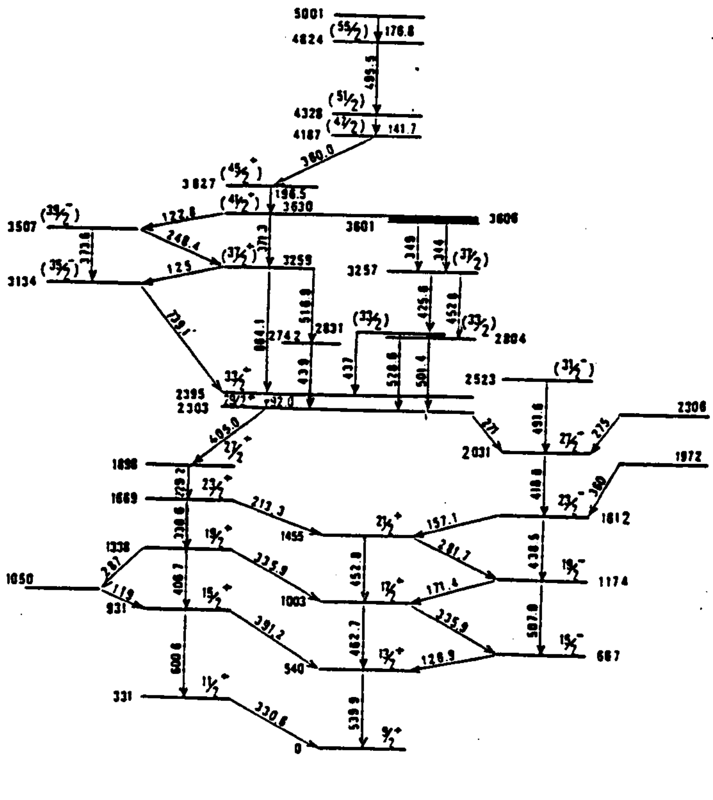
configuration	g_{calc}
$(\pi h_{9/2}{}^6)_{2+} \otimes (\nu g_{9/2}(i_{11/2}{}^2))_{29/2+}$	0.045(9)[a)]
$(\pi h_{9/2}{}^6)_{2+} \otimes (\nu g_{9/2}(i_{11/2}{}^2))_{29/2+}$	0.106(9)[b)]
$(\pi h_{9/2}{}^6)_{4+} \otimes (\nu g_{9/2}(i_{11/2}{}^2))_{25/2+}$	0.158(13)
$(\pi h_{9/2}{}^6)_{6+} \otimes (\nu g_{9/2}(i_{11/2}{}^2))_{21/2+}$	0.264(16)
$(\pi h_{9/2}{}^6)_{8+} \otimes (\nu g_{9/2}(i_{11/2}{}^2))_{17/2+}$	0.369(20)
$(\pi h_{9/2}{}^6)_{6+} \otimes (\nu g_{9/2}{}^3)_{21/2+}$	0.142(16)
$(\pi h_{9/2}{}^6)_{8+} \otimes (\nu g_{9/2}{}^3)_{17/2+}$	0.288(20)
$(\pi h_{9/2}{}^6)_{0+} \otimes (\nu g_{9/2}(j_{15/2}{}^2)_{12})_{33/2+}$	−0.200(18)
$(\pi h_{9/2}{}^6)_{0+} \otimes (\nu g_{9/2}(j_{15/2}{}^2)_{14})_{33/2^+}$	−0.188(21)
$(\pi h_{9/2}{}^5 i_{13/2})_{11-} \otimes (\nu g_{9/2}{}^2 j_{15/2})_{11/2-}$	0.697(12)

a) $g(2^+) = 0.406$: assumed the collective 2^+ state.
b) $g(2^+) = 0.909$: assumed the single particle 2^+ state.

Table 3. Experimental and theoretical g-factors for the states constituting the configurations in Table 2.

state	g
2^+ in ^{214}Ra	0.406[a)]
2^+ in ^{214}Ra: $(\pi h_{9/2}{}^6)_{2+}$	0.909(40)[b)]
$2^+ \sim 8^+$ in ^{214}Ra: $(\pi h_{9/2}{}^6)_{4+\sim 8+}$	0.909(40)[b)]
11^- in ^{214}Ra: $(\pi h_{9/2}{}^5 i_{13/2})_{11^-}$	1.085(10)[c)]
$\nu g_{9/2}$	−0.296(11)[d)]
$\nu i_{11/2}$	−0.126(12)[e)]
$\nu j_{15/2}$	−0.164(16)[e)]

a) g = Z/A: the collective g-factor.
b) experimental g-factor of $h_{9/2}$ proton[4)]: assuming $\pi h_{9/2}{}^6$ configuration for $2^+ \sim 8^+$ states in ^{214}Ra.
c) experimental value by Horn et al.[5)]
d) experimental value by Schröder and Toshinski et al.[6)]
e) theoretical g-factors by Bauer et al.[7)] with an assumed error of 10 %.



^{217}Ra

Fig. 1. A level scheme of ^{217}Ra proposed in Ref. 3.

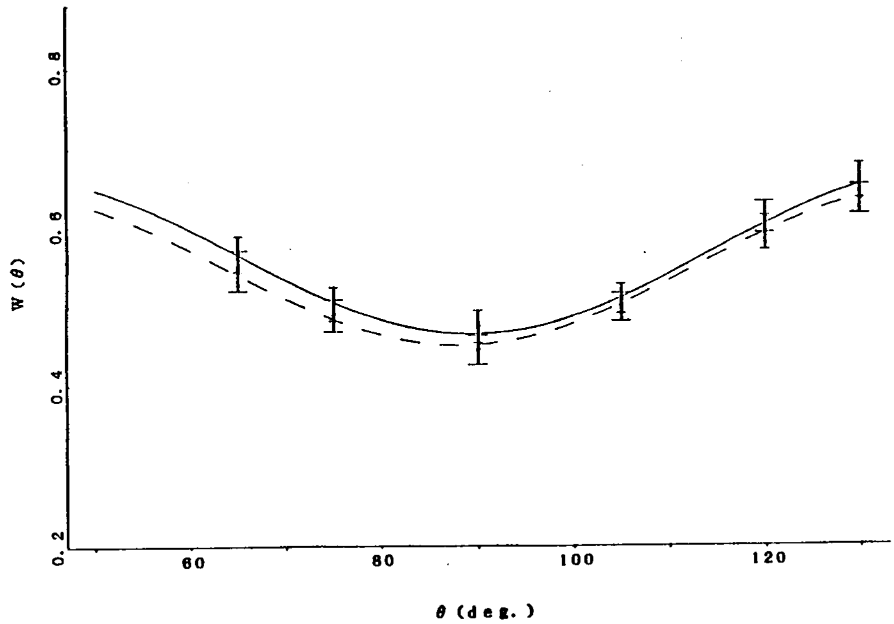


Fig. 2. Time integral perturbed angular distributions of the 229 keV γ-ray from the $^{208}Pb(^{12}C,3n)^{217}Ra$ reaction at $E(^{12}C) = 67$ MeV and $B_{eff} = \pm 2.001$ T. The solid and dashed curves are the results of the least squares fit.

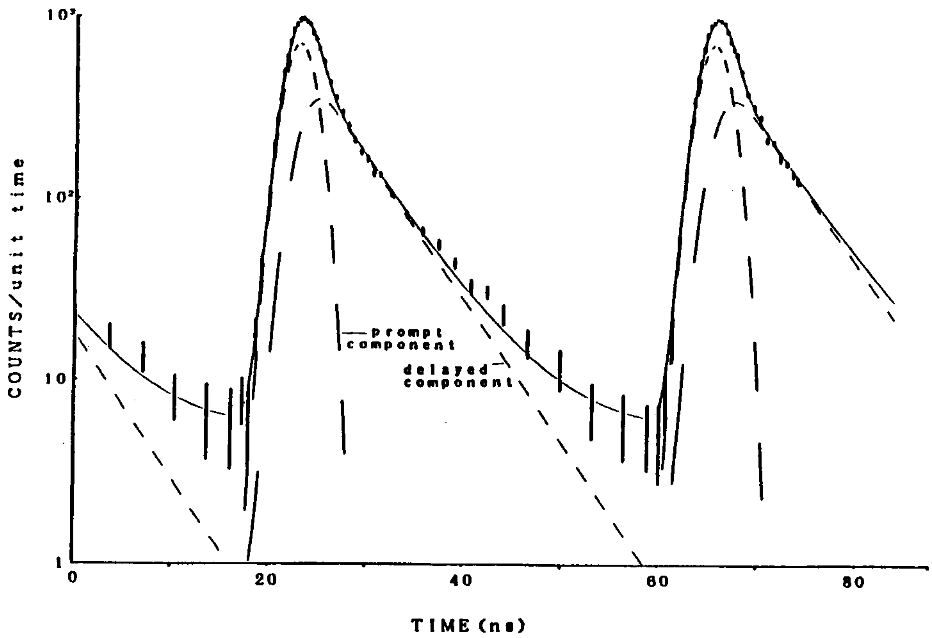


Fig. 3. Time spectrum of the 229 keV γ-ray in ^{217}Ra. Prompt and delayed components deduced by the least squares fit are indicated by the dashed lines. The solid line denotes the sum of the two components.