I. 5. Nuclear g-Factor of the 1579 keV $^3$ Isomer in $^{146}$Gd and the Paramagnetic Correction Factor of the Gd Ions in Samarium Oxide


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The first $^3$ excited states for doubly even N=82 nuclei with 54≤Z≤64 are considered as octupole excitations between orbits $2d_{5/2}$ and $1h_{11/2}^3$. The wave functions obtained from a calculation of the particle-core coupling also show a nearly pure $\pi[(2d_{5/2})^{-1}(1h_{11/2})^1]_3$ character. On the other hand the half-life of the $^3$ level in $^{146}$Gd found to be 1.06(12) ns$^3$ corresponds to an E3 strength of 37 Weisskopf units for the transition from the $^3$ isomer to the $0^+$ ground state. This indicates a feature of the collective motion rather than the single particle.

The nuclear g-factor may provide useful information to study the excitation mechanism of the $^3$ states. However there are no experimental data, only the g-factor of the $^3$ isomer in $^{146}$Gd is known to be 0.7(3)$^4$, and it is difficult to draw a conclusion from the value due to the relatively large error. We therefore have been remeasured the nuclear g-factor of the 1549 keV $^3$ isomer in $^{146}$Gd using the $^{144}$Sm($\alpha$,$2n$)$^{146}$Gd reaction and the time-integral perturbed angular distribution (TIPAD) method for in-beam $\gamma$-rays. The $^{146}$Gd nuclei were populated by the $^{144}$Sm($\alpha$,$2n$)$^{146}$Gd reaction using an $\alpha$-beam of 23.5 MeV from the CYRIC cyclotron. The beam energy was determined by excitation-function measurements so as not to disturb the TIPAD of the $^3$ isomer by the excitation of levels lying above 1579 keV. An enriched $^{144}$Sm$_2$O$_3$ target of 11 mg/cm$^2$ thickness was placed in an external magnetic field of ±1.81(l) T applied perpendicularly to the beam-detector plane.

The time-integral perturbed angular distributions (TIPAD) of the 1579 keV in-beam $\gamma$-rays emitted from the $^3$ isomer were measured with a 230 cm$^3$ HPGe detector at seven angles between 64 and 130 degrees.

The TIPAD data were fitted to an expression:

$$W(\theta \pm \Delta \theta) = A_0 + \sum_n A_n P_n \cos [n(\theta \pm \theta_0)], \quad (n = 2 \text{ and } 4),$$
where $\Delta \theta_n$ is the angular shift due to the Larmor precession, and given by the Larmor angular velocity $\omega$ and mean life $\tau$ as

$$\Delta \theta_n = (1/n)\tan^{-1}(n \omega \tau); \quad (n=2 \text{ and } 4).$$

The results of the least-squares fits are shown in table 1.

The nuclear g-factor is deduced from the Larmor angular velocity $\omega$ as

$$g=\hbar \omega /\mu_N B_{\text{eff}},$$

where $\mu_N$ is the nuclear magneton and $B_{\text{eff}}$ is the effective magnetic field at the site of Gd nuclei in the target.

The effective magnetic fields for rare-earth ions are quite different from the external field $B_{\text{ext}}$ by the large paramagnetic effect$^5)$. The $B_{\text{eff}}$ is written as

$$B_{\text{eff}} = \beta B_{\text{ext}},$$

where $\beta$ is the paramagnetic correction factor.

In order to deduce the g-factor from the experimental $\Delta \theta_n$ of the TIPAD, another experiment was carried out to obtain the $\beta$ for Gd nuclei in the Sm$_2$O$_3$ target. We took the 2982 keV 7$^-$ isomer with the half-life of 6.7(2) ns$^3$ in $^{146}$Gd of which the g-factor was known$^{4,6,7)$. TIPADs similar to those for 1579 keV $\gamma$-ray were measured at $B_{\text{ext}}=\pm 1.21(1)$ T for the 324 keV $\gamma$-ray from the transition between the 2982 keV 7$^-$ and the 2658 keV 5$^+$ levels.

The least-squares results of the TIPAD of the 324 keV $\gamma$-ray are also listed in table 1. A strong attenuation of the $A_2$ coefficient for the 324 keV $\gamma$-ray is observed. It may be due to a rapid relaxation of the alignment and is responsible for errors of the $\omega \tau$ and consequently of the $\beta$.

Using a weighted-mean g-factor, $g(7^-)=1.251(23)$, of refs. 4, 6 and 7, we have deduced the paramagnetic correction factor to be

$$\beta = 0.59 \ (11)$$

from the $\omega \tau$ in the table 1 and $B_{\text{ext}}=1.21(1)$ T. From a comparison between the present $\beta$ and theoretical values$^5)$ it is suggested that the Gd ions populated in Sm$_2$O$_3$ by nuclear reactions are in a mixed ion state with valence values of 3 and 4.

Using the present $\beta$ the g-factor of the 3$^+$ isomer is obtained to be

$$g(3^+ \text{ in } ^{146}\text{Gd}) = 1.00(22).$$

The major part of the error is caused by that of the $\beta$.

Possible configurations for a low-lying 3$^+$ state in $^{146}$Gd are listed in table 2 together with expected g-factors which were calculated using experimental g-factors for single-particle(or hole) components$^8)$. The present result is in good agreement with the expected g-
factor for \(\pi[(2d_{5/2})^{-1}(1h_{11/2})^3]3^-\) configuration, which indicates that the 3\(^-\) isomer in \(^{146}\text{Gd}\) has this configuration as a main component. However, the enhancement of the E3 transition from the isomer to ground state suggests also a possibility of a coherent mixture of many one particle one hole excitations due to the existence of the ground state correlations\(^9\). These correlations may be responsible for the enhancement of the electromagnetic transition rates.

References


Table 1. Experimental results of TIPADs.

<table>
<thead>
<tr>
<th>Isomer [keV, J^\pi, \tau (ns)]</th>
<th>A2</th>
<th>A4</th>
<th>\omega \tau (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1579, 3^-, 1.06(12)]</td>
<td>0.43(3)</td>
<td>0.046(29)</td>
<td>-0.0824(58)</td>
</tr>
<tr>
<td>[2982, 7^-, 6.7(2)]</td>
<td>0.087(32)</td>
<td>0.035(30)</td>
<td>-0.413(79)</td>
</tr>
</tbody>
</table>

No corrections were made for A2 and A4 coefficients.

Table 2. Expected g-factors for possible configurations.

<table>
<thead>
<tr>
<th>configuration</th>
<th>g(expected)</th>
<th>g(s.p/s.h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\pi(2d_{5/2}/2h_{11/2})^3^-)</td>
<td>1.167(5)</td>
<td>(g(\pi d_{5/2})=1.481(1)^a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(g(\pi h_{11/2})=1.288(3)^a)</td>
</tr>
<tr>
<td>(\pi(2g_{7/2}/2h_{11/2})^3^-)</td>
<td>1.437(11)</td>
<td>(g(\pi g_{7/2})=0.80(1)^b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(g(\nu f_{7/2})=-0.304^c)</td>
</tr>
<tr>
<td>(\nu(3s_{1/2}/2f_{7/2})^3^-)</td>
<td>-0.304(2)</td>
<td>(g(\nu s_{1/2})=-1.54^d)</td>
</tr>
</tbody>
</table>

a) taken from g(5/2\(^+\)) and g(11/2\(^-\)) of 145.147,149\(_{\text{Eu}}^8\)
b) g(7/2\(^+\)) of 141\(_{\text{Pr}}^8\)
c) g(7/2\(^-\)) of 143\(_{\text{Nd}}^8\)
d) g(1/2\(^+\)) of 133\(_{\text{Ba}}^8\)