INTENSITIES OF PARTIAL RADIATIVE TRANSITIONS TO ROTATIONAL AND VIBRATIONAL BANDS OF Gd^{155} AND Gd^{157} RESONANCES

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The total intensities of γ transitions to rotational and vibrational band levels in Gd^{155} and Gd^{157} resonances for captured neutron energies up to 150 eV are measured with a two-crystal scintillation spectrometer. An analysis of the experimental data indicates the existence of correlation between the intensities of transitions to the rotational band and the spins of the initial Gd^{155} states. Probable assignments of Gd^{155} capture state spins are made.

INTRODUCTION

THE measurements of partial radiative widths are in most instances consistent with statistical nuclear theory. However, in some cases individual properties of nuclei and their levels are observed. Among these are the observed anomalies of transition intensities for several rare-earth elements: Gd^{155}, Gd^{157}, and Dy^{163}. In the γ spectra of Gd^{155} and Gd^{157} induced by thermal neutron capture the partial transitions to the 2^+ (K = 0) level of the rotational band are 30 times less intense in Gd^{155} and 240 times less intense in Gd^{157} than the partial transitions to the 2^+ (K = 2) levels of the vibrational band.

In[1] we measured the total intensities of transitions to the rotational band in 23 resonances of Gd^{155}. In the present paper we present analogous measurements for 21 resonances of Gd^{157}. The available experimental data were also used to obtain total intensities of transitions to the vibrational band for each isotope.

EXPERIMENT

For our measurements of capture γ rays from individual resonances the neutron energies were determined by the time-of-flight technique. The neutron source was the linear electron accelerator of the I. V. Kurchatov Atomic Energy Institute. The spectrometer did not permit us to distinguish individual γ transitions. We therefore determined the summed relative intensities $J_{\gamma\,\mathrm{rot}}$ of transitions to 0^+ and 2^+ rotational levels (Gd^{155} and Gd^{157} capture states have the possible assignments 1^- and 2^-) and $J_{\gamma\,\mathrm{vib}}$ to the group of levels in the vibrational band region with ~1.15-MeV excitation energy. The latter included seven to eight levels, of which three or four have negative parity. In determining $J_{\gamma\,\mathrm{vib}}$ we subtracted the contribution from higher-energy transitions; Fe(n, γ) and Ni(n, γ) spectra were used for the purpose of calibration.

RESULTS

Tables I and II give the relative intensities $J_{\gamma\,\mathrm{rot}}$ and $J_{\gamma\,\mathrm{vib}}$ of the partial transitions and the ratios $J_{\gamma\,\mathrm{vib}}/J_{\gamma\,\mathrm{rot}}$. To obtain the ratios we did not simply divide $J_{\gamma\,\mathrm{vib}}$ by $J_{\gamma\,\mathrm{rot}}$, but used the original experimental spectra directly to permit greater accuracy.

The total intensities given for Gd^{155} are derived from our earlier work[1], where we made preliminary assignments of spins to some of the capture states on the basis of two factors: (1) the existence of a considerable number of weak transitions, permitting us to approximate the experimental intensity distribution using two Porter-Thomas distributions with average intensities differing by a factor of about six, and (2) the intensities of two-step cascade transitions (using the method of Bollinger[2]).

A comparison with the Porter-Thomas curves showed that the $J_{\gamma\,\mathrm{vib}}$ distribution corresponded to $\nu = 3 \pm 0.6$. Table I gives $J_{\gamma\,\mathrm{vib}}/J_{\gamma\,\mathrm{rot}} = z$ for each resonance. In all of the following calculations the thermal point was disregarded. For both Gd^{155} and Gd^{157} the value of z at the thermal point is about one-fourth of the value obtained from the thermal spectrum of the reactor using a Compton magnetic spectrometer. The discrepancy could result from the use of different neutron spectra, from a low value of $J_{\gamma\,\mathrm{rot}}$ at the thermal point, or from a neglected systematic error. We therefore consider our results to be less reliable at the thermal point than for resonances where the experimental conditions differed from those at the thermal point.

A statistical calculation of the ratio z averaged over both spin states, based on the known Gd^{155} level scheme, yields the value 2. It was assumed that for transitions of identical multipolarity the intensities depend only on energy according to an E_γ^5 law, and that the E1/M1 intensity ratio is given by an equation in[3]. The experimental value of z averaged over all levels is 3.0 ± 0.4 (omitting the level at 7.8 eV). The experimental data for $J_{\gamma\,\mathrm{vib}}/J_{\gamma\,\mathrm{rot}}$ therefore show that in Gd^{155} the partial transitions to rotational levels are inhibited as compared with transitions to vibrational levels.

The possibility of dividing the measured values of $J_{\gamma\,\mathrm{rot}}$ into two groups with different averages (the lower average pertaining to 2^- capture states) enables us to assign probable spins to Gd^{155} levels. The problem here was to determine the probability of a 2^- or 1^- assignment for the i-th resonance using the intensity $J^i_{\gamma\,\mathrm{rot}}$. The experimental distribution was regarded as the sum of two Porter-Thomas distributions, $\rho_1\xi_1 f(\nu_1,\ \xi_1 J^i_{\gamma\,\mathrm{rot}})$

Table I. Gadolinium 155

No.	E_0 of the resonance, eV	J_γ rot ($\bar{E}_\gamma$ = 8.48 MeV)	J_γ vib ($\bar{E}_\gamma$ = 7.32 MeV)	$\frac{J_\gamma \text{ vib}}{J_\gamma \text{ rot}}$	Level spin*	$P(1^-)/P(2^-)$
1	62.9	1.9±0.9	5.7±8	8.3±2.5	2 *	5.8
2	59.5	0.4±0.2	1.6±1.7	4.0±3.8	2 *	16
3	53.0	1.6±0.5	3.7±2.6	2.2±1.5	2 *	6.7
4	50.3	8.5±0.5	11.4±3.5	1.3±0.4	—	1
5	47.1	4.9±0.9	3.8±1.4	0.8±0.3	—	2.3
6	42.7	100.0±2.2	20±14	0.20±0.15	1 *	$3\cdot 10^{-7}$
7	37.3	12.2±1.6	4.9±2.6	0.4±0.2	—	0.5
8	35.1	20.4±4.9	26±9	1.3±0.3	1 *	0.095
9	33.8	9.8±0.7	18±9	1.8±1	—	0.8
10	30.5	1.2±1.2	7.2±7.4	6±3	2 *	8
11	29.9	0.8±0.4	6.0±5.7	7.5±6.5	2 *	11
12	23.3	15.8±1.3	3.0±4.4	0.2±0.3	1 *	0.25
13	21.3	14.3±1.4	8.4±1.9	0.57±0.12	—	0.31
14	20.2	1.5±0.8	12±9	7.9±4.9	2 *	7
15	14.64	2.3±1.0	15.1±8.2	6.5±2.4	2 *	5
16	12.06	4.4±0.8	9.8±2.6	2.2±0.4	—	2.6
17	11.67	44.8±4	3.3±3.6	0.07±0.08	1 *	0.016
18	10.12	1.5±0.7	4.4±5.2	2.9±3.3	2 *	4.3
19	7.8	0.01±0.07	0.16±1.0	16±6	2 *	100
20	6.3	2.0±0.5	9.8±4.2	4.9±1.8	2	3.3
21	2.57	4.6±2.0	3.9±2.2	0.84±0.3	2	2.5
22	2.01	7.9±1.1	2.9±1.5	0.36±0.2	1	1.1
23	0.0268	3.6±0.8	40±11	11±2	2	3.3

*Asterisks designate suggested spins.

Table II. Gadolinium 157

No.	E_0 of the resonance, eV	J_γ rot ($\bar{E}_\gamma$ = 7.9 MeV)	J_γ vib ($\bar{E}_\gamma$ = 6.7 MeV)	$\frac{J_\gamma \text{ vib}}{J_\gamma \text{ rot}}$
1	146.37	13.5±2.4	12.7±5.5	0.94±0.35
2	138.7 (139.6)	50±13	105±33	2.1±0.34
3	121.34	34±4	54±13	1.6±0.3
4	115.82	40±7	80±20	1.9±0.3
5	110.96	37±5	110±20	3.0±0.43
6	105.32	24±4	27±11	1.16±0.43
7	100.53	6.8±2.7	22±11	3.25±0.9
8	96.53	19±9	50±28	2.7±0.6
9	87.46	4±16	—	—
10	81.58 82.36	46±8	87±22	1.9±0.3
11	66.72	100±3	4.5±4.6	0.05±0.05
12	58.48	28±1.3	60±7.6	2.16±0.24
13	48.53	14±4.3	27±10	1.9±0.6
14	44.24	19±8	66±38	3.5±0.6
15	40.18	36±5	111±16	3.12±0.36
16	25.41	33±5	47±12	1.45±0.22
17	23.32	63±5.5	22±11	0.34±0.2
18	20.57	2.5±0.9	24±10	11.3±4.6
19	16.81	14±2.5	42±10	3.1±0.3
20	2.83	18±3.5	4±2.8	0.23±0.15
21	0.0314	0.34±0.24	12±10	36±12

and $\rho_2\zeta_2 f(\nu_2, \zeta_2 J^2_{\gamma\,\mathrm{rot}})$, determined from the degrees of freedom ν_1 and ν_2, the "extension" coefficients ζ_1 and ζ_2,[1)] and the statistical weights ρ_1 and ρ_2. The experimental distribution $f_{\exp}(J_{\gamma\,\mathrm{rot}})$ was normalized to yield the average $\bar{J}_{\gamma\,\mathrm{rot}} = 1$. If $\bar{J}^1_{\gamma\,\mathrm{rot}}$ and $\bar{J}^2_{\gamma\,\mathrm{rot}}$ are the averages for the two fitted Porter-Thomas distributions, they must satisfy the condition

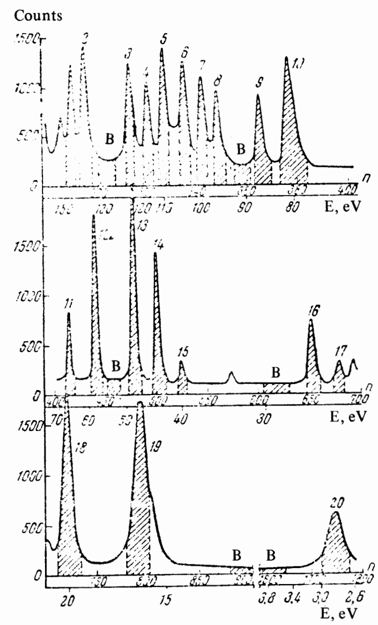
$$\bar{J}^1_{\gamma\,\mathrm{rot}}\rho_1 + \bar{J}^2_{\gamma\,\mathrm{rot}}\rho_2 = 1. \qquad (1)$$

The parameters of the Porter-Thomas distributions should, of course, yield the best fit of their sum to the experimental distribution.

For a given value of $J^i_{\gamma\,\mathrm{rot}}$ the ratio of the probabilities for assigning the i-th resonance to distribution 1 or 2 (and, accordingly, of assigning 1^- or 2^- to the capture state) will be

$$P(1^-)/P(2^-) = \frac{\rho_1\zeta_1 f(\nu_1, \zeta_1 J^i_{\gamma\,\mathrm{rot}})}{\rho_2\zeta_2 f(\nu_2, \zeta_2 J^i_{\gamma\,\mathrm{rot}})}. \qquad (2)$$

[1)]The distribution $f(\nu, J_{\gamma\mathrm{rot}})$ is taken to be normalized so as to yield the average $J_{\gamma\mathrm{rot}} = 1$. Then ζ_2/ζ_1, equals the ratio of the averages for distributions 1 and 2.



Experimental Gd^{157} cross sections. The hatched regions indicate where the γ-transition intensities were measured. The resonances are numbered serially as in Table II. Regions where the background was measured are designated by the letter B.

Table I gives the calculated probability ratios for the 1^- and 2^- states, and the more probable spins (marked with an asterisk). In our calculations we assumed

$$\bar{J}^1_{\gamma\,\mathrm{rot}}/\bar{J}^2_{\gamma\,\mathrm{rot}} = 10, \quad \rho_1 = 0.6\rho_2, \quad \nu_1 = 2, \ \nu_1 = 1. \qquad (3)$$

In the case of Gd^{157} (Table II) the intensities $J_{\gamma\,\mathrm{rot}}$ and $J_{\gamma\,\mathrm{vib}}$ are approximated separately by Porter-Thomas distributions with $\nu = 3 \pm 0.5$. The experimental $J_{\gamma\,\mathrm{rot}}$ distribution does not reveal a two-component structure. The ratio $J_{\gamma\,\mathrm{vib}}/J_{\gamma\,\mathrm{rot}} = 2.5 \pm 0.3$ obtained by averaging over all the measured resonances (seen in the figure) is about twice as large as the value obtained on the basis of the statistical analysis. This result can indicate some inhibition of transitions to the rotational band as compared with transitions to the vibrational band.

[1] L. S. Danelyan, B. V. Efimov, and S. K. Sotnikov, Zh. Eksp. Teor. Fiz. 54, 401 (1968) [Sov. Phys.-JETP 27, 216 (1968)].

[2] L. M. Bollinger and R. E. Coté, Bull. Am. Phys. Soc. 5, 294 (1960).

[3] L. M. Bollinger, Radiative Transitions from Highly Excited Nuclear States, reported at the International Symposium on Nuclear Structure at Dubna, 1968.

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