

$^{160}\text{Gd}(\gamma, \gamma')$ 1994Fr03,1989Pi05

Type	Author	History Citation	Literature Cutoff Date
Full Evaluation	N. Nica	NDS 176, 1 (2021)	1-May-2021

Additional information 1.

1989Pi05: enriched (98.6% ^{160}Gd) target in oxide form, irradiated with bremsstrahlung beam of endpoint energy 4.3 MeV. The scattered radiation was detected at scattering angles of 90° (or 95°), 127° and 150° using Ge(Li) and HPGe detectors. Typical energy resolution is 3.5 keV at 3 MeV. Overall accuracy of level energies is 1 keV. Since the deexciting transitions to levels above the first 2^+ rotational state were not observed, in deducing the ground-state widths, $\Gamma_{\gamma 0}$, the authors assume a branching of 5% to higher-lying β - and γ -vibrational bands.

1994Fr03: this work extends the earlier nuclear resonance-fluorescence studies of the even isotopes of Gd by this group (see **1989Pi05**) to include linear polarization measurements of resonantly scattered photons. The scattering target was a cylindrical disc of Gd_2O_3 (6.91 g, 98.1% ^{160}Gd) 2.7 cm in diameter sandwiched between two Al plates (total Al mass=3.02 g), which served as an on-line monitor of the γ -ray polarimeters. The sample was irradiated with a bremsstrahlung beam of endpoint energy 3.7 MeV. The scattered radiation was detected in two separate polarimeter systems. One was a 5-crystal Compton polarimeter having a central Ge detector and four peripheral Ge or Ge(Li) detectors located below the target. The second was a true-coaxial HPGe detector split into four electrically separated sectors and located in a horizontal scattering plane at a scattering angle of 99° . E_γ , I_γ , $\gamma(\theta)$ and the azimuthal asymmetry of the scattered radiation were measured. J^π and $\Gamma_{\gamma 0}$ values were deduced for the excited levels. See **1993Fr06** for a summary of some of these results, with application to the nature of the $2471, 1^-$ level.

Other (γ, γ') measurement: **1984Be54**.

1995An28, from the (p, p') reaction at $E(p)=22$ MeV, study the question of whether the group of "M1-excitation" states between ≈ 3.1 and 3.5 MeV are of spin or of orbital character. From the absence of these states in the (p, p') spectrum at 10° , **1995An28** conclude that these states are orbital in character. For other information on this experiment, see the (p, p') data set.

From the ratio of the reduced transition probabilities of the gammas deexciting a given level to the 0^+ and 2^+ members of the g.s. band, the authors deduce K values for the level, based on the Alaga rules. Transitions between levels for which $\Delta K=0$ are claimed to be E1, while those between levels having $\Delta K=1$ may be either E1 or M1.

Evidence for the mixing of K values in some of the collective $J=1$ states in a number of deformed rare-earth nuclides, including ^{160}Gd , has been presented by **1990Zi05**.

A theoretical study of the M1 strength distribution among the $K^\pi=1^+$ states in the even-mass Gd isotopes, including ^{160}Gd , has been carried out by **1989De42**.

Recent theoretical studies of the "scissors" mode and its fragmentation in several doubly even isotopes of Gd and Dy are described in **1998Be08** and **2000Be16**.

 ^{160}Gd Levels

Unless noted otherwise, the listed B(E1) and B(M1) values are those computed by the evaluator using the $\Gamma_{\gamma 0}$ values given here.

E(level) ^{†‡}	J^π [#]	$\Gamma_{\gamma 0}$ (meV) ^b	Comments
0.0	0^+		J^π : from adopted values.
75.26 <i>1</i>	2^+		E(level), J^π : from adopted values.
1224.8 <i>9</i>	1^-		B(E1) $\uparrow=1.9 \times 10^{-4}$ <i>5</i> E(level): 1989Pi05 report Γ -related data and B(E1) value for this level with level energy, J^π and γ branching from 1985Le21 . No data are given by 1994Fr03 . J^π : adopted value. Bandhead of $K^\pi=0^-$ octupole vibration.
1967 <i>1</i>	1^-	10.2 <i>12</i>	B(E1) \uparrow : from $\Gamma_{\gamma 0}^2/\Gamma=4.5$ meV <i>12</i> (1989Pi05). B(E1) $\uparrow=3.8 \times 10^{-5}$ <i>4</i> $\Gamma_{\gamma 0}^2/\Gamma=3.9$ meV <i>9</i> (1989Pi05).
2163 & <i>1</i>	1	4.6 <i>7</i>	
2278 & <i>1</i>	1	2.4 <i>6</i>	
2348 <i>1</i>	1^+	11.3 <i>8</i>	B(M1) $\uparrow=0.226$ <i>16</i>
2471 <i>1</i>	1^-	16.3 <i>23</i>	B(E1) $\uparrow=3.1 \times 10^{-5}$ <i>5</i> the large B(E1) value indicates an enhanced E1 transition

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$^{160}\text{Gd}(\gamma, \gamma')$ **1994Fr03, 1989Pi05 (continued)** ^{160}Gd Levels (continued)

<u>E(level)^{†‡}</u>	<u>J^π#</u>	<u>Γ_{γ0} (meV)^b</u>	<u>Comments</u>
			(1989Pi05, 1993Fr06, 1994Fr03). It has been used by these authors as evidence supporting the interpretation of this level as a collective electric-dipole excitation arising from, for example, a reflection-asymmetric shape and/or a cluster configuration. 1993Kn01 present evidence suggesting that it may be a two-phonon octupole-γ-vibrational excitation.
2670 <i>l</i>	1 ⁺	14.3 <i>l0</i>	B(M1)↑=0.195 <i>l4</i>
2761 & <i>l</i>	1	5.5 <i>l4</i>	
2796 <i>l</i>	1 ⁺	64 <i>4</i>	B(M1)↑=0.76 <i>5</i>
2820 & <i>l</i>	1 ⁽⁺⁾	17 <i>3</i>	B(M1)↑=0.20 <i>4</i>
2999 & <i>l</i>	1	4.4 <i>7</i>	
3032 <i>l</i>	1 ⁻	12.5 <i>l6</i>	B(E1)↑=1.28×10 ⁻⁵ <i>l6</i>
3131 <i>l</i>	1 ⁻	23.4 <i>2l</i>	B(E1)↑=2.18×10 ⁻⁵ <i>20</i>
3166 <i>l</i>	1 ⁽⁻⁾	25 <i>3</i>	B(E1)↑=2.3×10 ⁻⁵ <i>3</i>
3170 ^a <i>l</i>	1 ⁺	51 <i>5</i>	B(M1)↑=0.42 <i>4</i>
3228 & <i>l</i>	1	8.9 <i>l8</i>	
3277 ^a <i>l</i>	1 ⁺	77 <i>6</i>	B(M1)↑=0.57 <i>4</i>
3292 & <i>l</i>	1	8.3 <i>l3</i>	
3308 ^a <i>l</i>	1 ⁺	60 <i>5</i>	B(M1)↑=0.43 <i>4</i>
3328 @ <i>l</i>	1		
3331 @ ^a <i>l</i>	1 ⁺	31 <i>4</i>	B(M1)↑=0.22 <i>3</i>
3340 & ^a <i>l</i>	1 ⁺	36 <i>4</i>	B(M1)↑=0.25 <i>3</i>
3357 & <i>l</i>	1	18.2 <i>25</i>	
3376 & <i>l</i>	1	21 <i>3</i>	
3415 <i>l</i>	1 ⁻	57 <i>6</i>	B(E1)↑=4.1×10 ⁻⁵ <i>4</i>
3460 <i>l</i>	1 ⁻	49 <i>6</i>	B(E1)↑=3.4×10 ⁻⁵ <i>4</i>
3477 & <i>l</i>	1 ⁽⁺⁾	52 <i>9</i>	B(M1)↑=0.32 <i>6</i>
3537 & <i>l</i>	1	23 <i>5</i>	
3550 & <i>l</i>	1	29 <i>7</i>	

[†] 1989Pi05 report a level at 3523 with I_γ(γ to 2⁺)/I_γ(γ to 0⁺)=2.3 9. 1994Fr03 report levels in this general region but do not report one at or near this energy. This level is not included in the table.

[‡] Except where noted otherwise, the level energies are those reported by 1994Fr03. These authors do not give uncertainties for these values. The evaluator has assumed that these uncertainties are nominally 1 keV, based on the observation that earlier, similar work from this group (1989Pi05) reported 1-keV uncertainties in E(level).

Unless otherwise noted, the J values are based on the dipole character of the associated γ excitation, as determined from the angular-distribution data. The π values are obtained from the γ-ray linear polarization, noting that the π=+ for the ground and first-excited states. Since most of these levels are seen only in (γ, γ'), these values are the same as the Adopted Values.

@ 1989Pi05 report levels at 3328 and 3331, but do not indicate how the γ intensity deexciting them is to be allocated. 1994Fr03 state that there are two levels, not resolved, here and list 3331 for the energy. They also list J^π, I_γ and Γ_{γ0} data for this "3331 level". The evaluator has assumed that this information is to be associated with the 3331 level only.

& Level not reported by 1989Pi05.

^a From the absence of this state in the (p, p') spectrum at θ=10°, 1995An28 conclude that this level is orbital, rather than spin, in character.

^b Where both 1989Pi05 and 1994Fr03 report the level, the listed value is the weighted average of those reported in the two studies. Where only one study reports the level, the value is from that work only. Note that the authors have increased by 5% the Γ_{γ0} values deduced from the measured Γ_{γ0}²/Γ and Γ₂₊/Γ₀₊ to allow for possible missed transitions.

$^{160}\text{Gd}(\gamma, \gamma')$ **1994Fr03, 1989Pi05 (continued)**

$E_i(\text{level})$	J_i^π	E_γ^\dagger	I_γ^\ddagger	E_f	J_f^π	Mult. #	$\gamma(^{160}\text{Gd})$	Comments
1224.8	1^-	1149.18 15	100 2	75.26	2^+			E_γ, I_γ : from adopted values. 1989Pi05 take their γ -branching data for this level from other sources. 1994Fr03 do not present data on this level.
		1225.0 5	64 2	0.0	0^+	(E1)		E_γ, I_γ : 1989Pi05 take energy and γ -branching data for this level from 1985Le21. No data are given by 1994Fr03. Mult.: dipole excitation in (γ, γ') (1989Pi05). Ratio of reduced transition probabilities of transitions to 0^+ and 2^+ members of g.s. band agree well with predictions of Alaga rules for $\Delta K=0$, which is, according to 1989Pi05, indicative of an E1 transition.
1967	1^-	1892 1	166 15	75.26	2^+			
		1967 1	100	0.0	0^+	E1		
2163	1	2088 1	59 16	75.26	2^+			
		2163 1	100	0.0	0^+	D		
2278	1	2203 1	73 24	75.26	2^+			
		2278 1	100	0.0	0^+	D		
2348	1^+	2273 1	50 5	75.26	2^+			
		2348 1	100	0.0	0^+	M1		
2471	1^-	2396 1	151 17	75.26	2^+			
		2471 1	100	0.0	0^+	E1		
2670	1^+	2595 1	53 4	75.26	2^+			
		2670 1	100	0.0	0^+	M1		
2761	1	2686 1	100	75.26	2^+			
		2761 1	56 12	0.0	0^+	D		
2796	1^+	2721 1	56 2	75.26	2^+			
		2796 1	100	0.0	0^+	M1		
2820	$1^{(+)}$	2745 1	132 19	75.26	2^+			
		2820 1	100	0.0	0^+	(M1)		
2999	1	2924 1	36 12	75.26	2^+			
		2999 1	100	0.0	0^+	D		
3032	1^-	2957 1	150 17	75.26	2^+			
		3032 1	100	0.0	0^+	E1		
3131	1^-	3056 1	84 7	75.26	2^+			I_γ : from 1994Fr03 only. 1989Pi05 report $I_\gamma(3056\gamma)=126$ 20, relative to $I_\gamma(3131\gamma)=100$.
		3131 1	100	0.0	0^+	E1		
3166	$1^{(-)}$	3091 1	64 11	75.26	2^+			I_γ : from 1994Fr03 only. 1989Pi05 do not report a split in intensity between this γ and the 3095 γ .
		3166 1	100	0.0	0^+	(E1)		I_γ : from 1994Fr03 only. 1989Pi05 do not report a split in intensity between this γ and the 3170 γ .
3170	1^+	3095 1	60 6	75.26	2^+			I_γ : from 1994Fr03 only. 1989Pi05 do not report a split in intensity between this γ and the 3091 γ .
		3170 1	100	0.0	0^+	M1		I_γ : from 1994Fr03 only. 1989Pi05 do not report a split in intensity between this γ and the 3166 γ .
3228	1	3153 1	104 20	75.26	2^+			
		3228 1	100	0.0	0^+	D		
3277	1^+	3202 1	54 4	75.26	2^+			
		3277 1	100	0.0	0^+	M1		
3292	1	3217 1	31 9	75.26	2^+			
		3292 1	100	0.0	0^+	D		
3308	1^+	3233 1	58 3	75.26	2^+			
		3308 1	100	0.0	0^+	M1		
3328	1	3253 1		75.26	2^+			I_γ : the split of intensity between the 3253 and 3256 γ 's is not given by 1989Pi05. The evaluator has assumed that the I_γ data of 1994Fr03 for the "3331 level" are to be associated with that level only.
		3328 1		0.0	0^+	D		I_γ : the split of intensity between the 3328 and 3331 γ 's is not

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$^{160}\text{Gd}(\gamma, \gamma')$ **1994Fr03, 1989Pi05 (continued)** $\gamma(^{160}\text{Gd})$ (continued)

$E_i(\text{level})$	J_i^π	E_γ^\dagger	I_γ^\ddagger	E_f	J_f^π	Mult. [#]	Comments
3331	1 ⁺	3256 <i>I</i>	46 5	75.26	2 ⁺		given by 1989Pi05. The evaluator has assumed that the I_γ data of 1994Fr03 for the "3331 level" are to be associated with that level only.
		3331 <i>I</i>	100	0.0	0 ⁺	M1	I_γ : from 1994Fr03. See the comment on the 3253 γ from the 3328 level.
							I_γ : from 1994Fr03. See the comment on the 3328 γ from the 3328 level.
3340	1 ⁺	3265 <i>I</i>	59 5	75.26	2 ⁺		
		3340 <i>I</i>	100	0.0	0 ⁺	M1	
3357	1	3282 <i>I</i>	40 6	75.26	2 ⁺		
		3357 <i>I</i>	100	0.0	0 ⁺	D	
3376	1	3301 <i>I</i>	43 5	75.26	2 ⁺		
		3376 <i>I</i>	100	0.0	0 ⁺	D	
3415	1 ⁻	3340 <i>I</i>	47 3	75.26	2 ⁺		I_γ : from 1994Fr03 only. 1989Pi05 report $I_\gamma(3340\gamma)=151\ 20$, relative to $I_\gamma(3415\gamma)=100$.
		3415 <i>I</i>	100	0.0	0 ⁺	E1	
3460	1 ⁻	3385 <i>I</i>	40 3	75.26	2 ⁺		
		3460 <i>I</i>	100	0.0	0 ⁺	E1	
3477	1 ⁽⁺⁾	3402 <i>I</i>	43 4	75.26	2 ⁺		
		3477 <i>I</i>	100	0.0	0 ⁺	(M1)	
3537	1	3462 <i>I</i>	47 5	75.26	2 ⁺		
		3537 <i>I</i>	100	0.0	0 ⁺	D	
3550	1	3475 <i>I</i>	40 7	75.26	2 ⁺		
		3550 <i>I</i>	100	0.0	0 ⁺	D	

[†] Values computed from the energy difference of the levels involved.

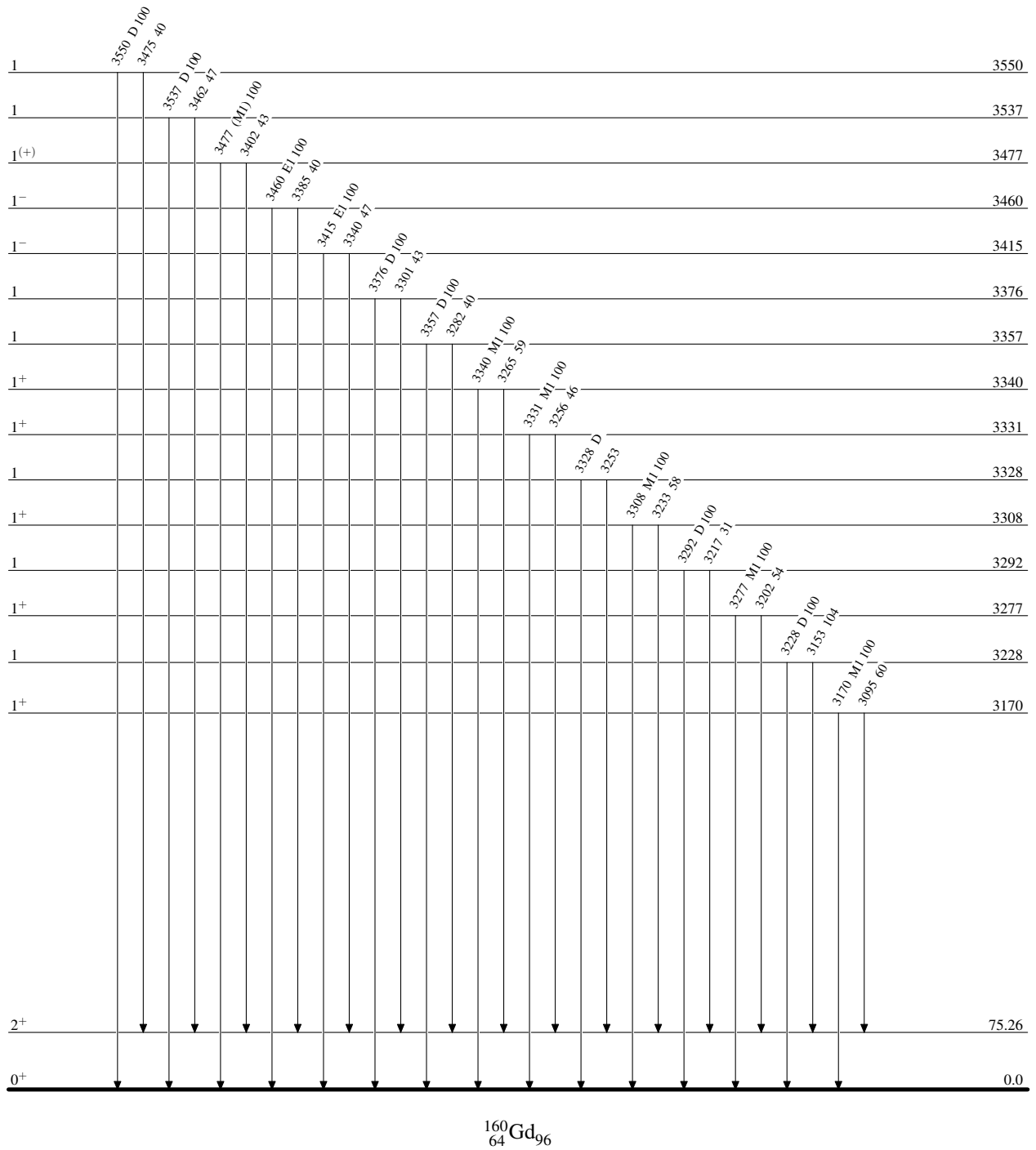
[‡] Relative intensities of the two gammas deexciting each level were obtained from the reported ratio of the decay widths of the level to the first 2⁺ state and the g.s. Unless otherwise noted, the listed values represent weighted averages of the data of 1994Fr03 and 1989Pi05.

[#] From the measured $W(90^\circ)/W(127^\circ)$ and/or linear polarization of the scattered photons (1994Fr03).

$^{160}\text{Gd}(\gamma,\gamma')$ 1994Fr03,1989Pi05

Level Scheme

Intensities: Relative photon branching from each level



$^{160}\text{Gd}(\gamma,\gamma')$ 1994Fr03,1989Pi05

Level Scheme (continued)

Intensities: Relative photon branching from each level

