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**J.Dupák, J.Ferencei, M.Finger, W.D.Hamilton,[1]
A.Jankech, J.Koníček, A.Machová,[2] J.Říkovská,[2]
A.F.Shchus**

NUCLEAR ORIENTATION OF ^{152,154}Tb IN GADOLINIUM

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[1] University of Sussex, Brighton, UK.
[2] Czech Technical University, Prague.

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Дупак Я. и др.

Ядерная ориентация ^{152,154}Tb в гадолинии

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Измерены асимметрии гамма-лучей ориентированных ядер ^{152,154}Tb в гадолинии. Измерения выполнены под углами 0 и 90° по отношению к направлению приложенного магнитного поля при температуре образцов /15 ± 1/ мК. Однозначно установлены значения спинов для ряда уровней в ^{152}Gd, а также определены значения параметров смешивания мультипольностей для большого числа гамма-переходов в этом ядре. Полученные результаты сравниваются с аналогичными данными для ядер ^{150,154,156}Gd. Проводится обсуждение экспериментальных результатов в рамках современных теоретических представлений. В работе установлены значения спинов для уровней 2277,0, 2336,1 и 2416,3 кэВ в ^{154}Gd : 3,3 и 4, соответственно, а также подтверждено значение спина I = 0 для изомера с $T_{1/2}$ = 21,4 час ^{154}Tb.

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Nuclear Orientation of ^{152,154}Tb in Gadolinium

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1. INTRODUCTION

Nuclear orientation of ^{152}Tb was studied for the first time by Kalfas et al.[1] in a gold matrix. Anisotropy for some gamma-ray transitions was obtained and four mixing ratios were deduced. These results indicate that some interesting information about the even-even "transitional" nucleus ^{152}Gd could be found if one uses a more intensive radioactive source in a more suitable ferromagnetic matrix.

Nuclear orientation of ^{154}Tb has not been measured yet. An extensive study of multipole mixing ratios of transitions in ^{154}Gd from the levels populated by the (α, 2nγ) reaction, using the in-beam angular distribution technique, has been reported recently[2]. The great uncertainty in assignments of high excited states with simple feeding from the decay of the 9.0 h ($I^{\pi} = 3^{\pm}$) isomer in ^{154}Tb and scarce electron-conversion data about multipolarities of transitions in question do not allow us to obtain similar information. Further, the existence of the long-lived 2137.8 keV level ($I \geq 7$) in ^{154}Gd influences anisotropies of transitions from excited states, associated with the 22.6 h ^{154}Tb isomer decay and populated via the state. Nevertheless, our nuclear orientation data are very useful in determining spin assignments of some excited states in ^{154}Gd. They have enabled us also to verify the I = = 0 spin value of the 21.4 h isomer in ^{154}Tb.

The present work has been performed to complete the information about the decay of doubly even terbium isotopes, which has been systematically investigated by the nuclear orientation method in recent years[3,4].

2. EXPERIMENTAL METHOD AND RESULTS

The ^{152}Tb ($T_{1/2}$ = 17.5 h) and ^{154}Tb ($T_{1/2}$ = 9 h, 21.4 h and 22.6 h) activities were produced as spallation products following the bombardment of Ta with 660 MeV protons in the Dubna synchrocyclotron. The sources for the nuclear orientation experiment were obtained by implanting radioactive ^{152,154}Tb atoms into a gadolinium matrix, heat-treating and cooling to low temperature. Gamma-ray spectra were measured at

Table 1.

Normalized intensities of gamma-ray transitions from the decay of ^{152}Tb.

E_γ [keV] a)	W^{exp} (0,T) b)	W^{exp} (π/2,T)	E_γ [keV] a)	W^{exp} (0,T) b)	W^{exp} (π/2,T)
315.2	0.83(5)	1.06(9)	985.1	0.65(17)	-
344.3	0.918(2)	1.074(3)	990.3	0.74(3)	1.12(3)
411.1	0.86(2)	1.06(2)	1010.7	0.75(4)	1.09(8)
526.9	0.97(2)	1.02(1)	1016.4	0.73(18)	-
543.7	1.13(4)	0.79(12)	1037.0	1.02(17)	0.71(24)
547.5	1.25(7)	-	1048.1	0.73(9)	-
586.3	1.093(4)	0.94(2)	1052.3	0.86(5)	-
622.8	0.62(1)	1.13(5)	1084.1	0.85(7)	-
675.1	0.81(3)	1.010(3)	1086.3	0.97(3)	1.06(15)
678.6	1.01(13)	0.90(16)	1089.9	0.93(3)	1.10(9)
764.9	0.89(1)	1.03(2)	1106.7	0.87(7)	-
778.9	1.045(9)	0.89(2)	1109.2	0.80(2)	1.06(4)
794.7	0.83(7)	1.07(5)	1131.0	0.87(9)	-
812.8	0.81(7)	-	1137.6	0.79(3)	1.04(5)
818.2	1.05(14)	0.60(15)	1185.6	0.86(5)	1.09(13)
893.3	0.69(3)	1.10(4)	1190.5	0.86(4)	1.05(15)
902.4	0.92(7)	1.41(45)	1209.1	1.09(5)	0.76(16)
909.1	1.06(11)	-	1261.4	0.82(3)	1.06(6)
928.7	1.07(12)	0.78(14)	1275.1	0.64(23)	-
930.7	0.84(3)	1.08(9)	1284.6	1.41(16)	-
937.0	1.12(10)	0.86(16)	1299.1	0.87(2)	1.05(4)
970.4	1.15(6)	0.86(9)	1314.7	1.02(3)	0.90(4)
974.1	0.76(2)	1.07(3)	1318.2	0.80(9)	1.12(13)

Table 1 (continued)

1325.8	0.68(3)	1.10(7)	1920.9	0.93(5)	1.02(9)
1336.6	0.90(9)	-	1941.1	0.68(3)	1.11(5)
1343	0.77(6)	-	1955.3	0.85(5)	1.08(7)
1348.1	1.05(2)	0.97(5)	2342.8	0.80(12)	-
1353	0.66(9)	-	2365.3	0.77(4)	1.17(8)
1517.8	0.94(5)	1.03(2)	2357.3	0.75(3)	1.10(4)
1586.2	0.96(3)	1.08(7)	2384.7	0.79(9)	1.18(17)
1667.4	0.88(4)	1.07(7)	2398.4	1.27(13)	0.78(20)
1757.4	1.10(5)	0.90(9)	2405.0	1.06(3)	0.94(8)
1771.4	0.79(5)	1.23(14)	2584.7	1.20(12)	-
1789.1	0.86(4)	1.04(3)	2588.3	0.77(7)	-
1809.8	0.84(8)	-	2619.7	0.86(4)	-
1857.3	1.27(7)	0.76(8)	2697.9	0.82(3)	-
1861.9	0.73(2)	1.04(8)	2709.4	0.72(6)	-
1902.4	1.160(7)	0.88(3)	2719.8	0.75(5)	-
1915.1	0.81(11)	-			

a) Gamma-ray energies taken from Ref. /5/.

b) An error in parentheses is given in units of the last decimal.

Table 2

Normalized intensities of some gamma-ray transitions from the decay of ^{154}Tb .

$T_{1/2}$ = 9.0 h [a)]					
E_γ [b)] [keV]	W^{exp} [c)] (0,T)	W^{exp} (π/2,T)	E_γ [b)] [keV]	W^{exp} [c)] (0,T)	W^{exp} (π/2,T)
415.8	1.07(4)	0.81(7)	1246.2	1.08(9)	0.75(25)
540.1	0.73(5)	1.19(4)	1258.1	1.18(5)	0.96(7)
922.1	0.74(10)	1.30(20)	1288.4	1.19(10)	-
953.1	0.99(6)	1.03(2)	1339.8	1.12(9)	-
965.1	0.88(9)	1.15(7)	1490.6	1.12(8)	0.83(9)
1084.3	0.87(10)	1.27(20)	1494.2	1.57(30)	0.59(34)
1101.9	1.34(6)	-	1619.2	1.11(5)	0.87(5)
1105.8	1.06(5)	-	1934.7	1.20(13)	0.89(8)
1149.1	0.85(8)	1.07(2)	1965.0	1.10(6)	0.94(1)
1152.1	0.65(11)	1.23(8)	2153.8	1.07(4)	0.90(7)
1208.1	0.74(5)	1.36(19)	2212.9	1.11(7)	0.85(2)
1229.2	1.18(9)	0.84(6)			

$T_{1/2}$ = 22.6 h [a)]					
E_γ [b)] [keV]	W^{exp} [c)] (0,T)	W^{exp} (π/2,T)	E_γ [b)] [keV]	W^{exp} [c)] (0,T)	W^{exp} (π/2,T)
141.4	0.96(6)	1.04(8)	565.5	1.05(7)	0.86(11)
172.1	1.53(10)	0.84(10)	993.0	0.95(3)	1.00(9)
226.1	0.87(8)	-	1061.2	1.25(9)	-
426.8	0.96(3)	1.03(5)	1419.9 [d)]	0.97(2)	1.03(3)

Table 2 (continued)

$T_{1/2}$ = 21.4 h [a)]					
E_γ [b)] [keV]	W^{exp} [c)] (0,T)	W^{exp} (π/2,T)	E_γ [b)] [keV]	W^{exp} [c)] (0,T)	W^{exp} (π/2,T)
705.0	1.00(5)	0.98(2)	1123.2	1.01(3)	0.94(11)
722.1	1.02(4)	1.01(3)	1291.3	0.99(4)	1.02(5)
878.3	0.98(4)	1.03(3)			

a) Lau and Hogan [6].
b) Gamma-ray energies are taken from Ref. [7] .
c) An error in parentheses is given in units of the last decimal.
d) The transition contains a small admixture of 1419.4 keV ($T_{1/2}$ = 9 h) transition.

angles 0 and $\pi/2$ with respect to the applied external magnetic field by two Ge(Li) detectors each with a sensitive volume of ~ 30 cm^3 and a resolution of 3 keV at 1332 keV. Further details regarding the experimental apparatus and data handling may be found in a previous work [4].

Normalized intensities $W^{exp}(\theta,T) = I^{\gamma}_{T=15\,mK}(\theta)/I^{\gamma}_{T\geq 500\,mK}(\theta)$ of gamma-ray transitions from the decay of ^{152}Tb and from the decay of all three isomers of ^{154}Tb have been deduced and summarized in Tables 1 and 2. Experimental errors of W^{exp} were determined using the method of Berglund et al. [8] .

3. DATA ANALYSIS

3.1. Spin Assignments of Levels in ^{152}Gd

Many excited levels in the decay scheme of ^{152}Tb , proposed by Zolnowski et al. /5/ have more than one possible value of spin. These ambiguities can be removed or reduced by using experimental values of angular distribution coefficients A_k . We have assumed as a starting point that the spin-parity assignments of Zolnowski et al. were correct. When multipole components of a transition were not known, the most probable values on the basis of Zolnowski's data were assumed. The following spin-parity values have been obtained: 3328 keV (1), 3042.2 keV (2^+), 3024 keV (2^+), 2265.2 keV(2^+), 2929 keV (3), 2687 keV (2^+), 2599 keV (2^+), 2265 keV (2^+), 2246.7 keV (1^+), 1915.4 keV (4^+), 1839.6 keV (4), 1692.4 keV (3^+). The parities have been determined on the basis of the dominant multipole component; if L = 2 multipole component is greater than 10% we assume $\Delta\pi = 0$. The 3^+ spin-parity value of the 2011.7 keV state given in Ref. /5/ seems to be rather 2^+ according to our results. Other assignments of states emitting gamma-rays with known anisotropy are consistent with the nuclear orientation data.

3.2. Gamma-Ray Multipole Mixing Ratios in ^{152}Gd

The values of the normalized intensities, given in Table 1 were used to determine the multipole mixing ratios, listed in Table 3. The convention for the sign of the multipole mixing ratio, δ , adopted in the present work is that of Krane and Steffen /10/. The anisotropies of the 893.3, 1325.8 and 1941.1 keV pure E2 transitions were used to obtain the values of B_2^{exp} and B_4^{exp} , assuming the beta-decay to the 1941.2 keV level to be allowed Gamow-Teller type. This yields the average values of B_2^{exp} and B_4^{exp} equal to 0.84 (29) and 0.096 (45), respectively, which were used in analysis of all other gamma-ray transitions, All the spectroscopic data necessary for the evaluation of the U_k coefficients were taken from the work of Zolnowski et al. /5/ and Adam et al. /11/. Gamma-ray transitions with unknown multipole mixing ratios were assumed to have the lowest possible multipolarity, allowed by selection rules. When a spin assignment of a level was not unique, all possibilities were taken into account. An error caused by these assumptions was estimated and it was included in the error of U_k . All beta-transitions, following

Table 3

Multipole mixing ratios of transitions in ^{152}Gd .

E_l [keV]$^{a)}$	U_2	U_4	E_γ [keV]$^{a)}$	$I_i^\pi \rightarrow I_f^\pi$	Mixing ratio b) Present work M2/E1	KRANE [9] M2/E1
2880.6	0.592	0.	1771.4	$1^- \rightarrow 2^+_\gamma$	1.11(61) c)	-
			1754.4	$1^- \rightarrow 3^-_{oct}$	$0.50^{+0.46}_{-0.29}$ d)	
2729	0.500	0.	1086.3	$2^+ \rightarrow 2^-_{oct}$	-0.18(14)	-
2709.4	0.500	0.	1586.2	$2^+ \rightarrow 3^-_{oct}$	-0.34(21)	-
2523.7	0.500	0.	1209.1	$2^+ \rightarrow 1^-_{oct}$	- 0.20(14)	-
2299.6	0.828	0.418	1955.3	$3^- \rightarrow 2^+_g$	$0.30^{+0.09}_{-0.08}$	-
			1190.5	$3^- \rightarrow 2^+_\gamma$	$0.28^{+0.17}_{-0.14}$	-
1643.4	0.476(19)	-0.644(26)	1299.1	$2^-_{oct} \rightarrow 2^+_g$	-0.10(8)	-
1314.7	0.343(22)	-0.165(10)	970.4	$1^-_{oct} \rightarrow 2^+_g$	$0.18^{+0.17}_{-0.21}$	-
1123.1	0.540(30)	-0.0898(49)	778.9	$3^-_{oct} \rightarrow 2^+_g$	0.011(63)	-
					E2/M1	E2/M1
2729	0.500	0.	2384.7	$2^+ \rightarrow 2^+_g$	$0.31^{+\infty}_{-0.52}$	-
2719.8	0.500	0.	2375.3	$2^+ \rightarrow 2^+_g$	$0.10^{+0.27}_{-0.18}$	-
			1789.1	$2^+ \rightarrow 2^+_\beta$	-0.13(10)	-

Table 3 (continued)

2709.4	0.500	0.	2365.3	$2^+ \to 2^+_g$	$0.31^{+\infty}_{-0.38}$	-
2246.7	0.587(30)	0.	1902.4	$1^+ \to 2^+_g$	$0.36^{+0.25}_{-0.18}$	-
			1137.6	$1^+ \to 2^+_\gamma$	$-0.69^{+0.46}_{-\infty}$	-
2201.6	0.828	0.418	1857.3	$3^+ \to 2^+_g$	-0.12(7) or	-
					$-2.6^{+0.9}_{-1.6}$	-
2011.7	0.828	0.418	1667.4	$2^+ \to 2^+_g$	$0.29^{+0.09}_{-0.08}$	-
1941.2	0.497(25)	-0.667	622.8	$2^+_{\gamma-2\beta} \to 2^+_{1\beta}$	1.04(50)	$0.7^{+0.8}_{-0.5}$
			1010.7	$2^+_{\gamma-2\beta} \to 2^+_\beta$	$1.88^{+1.93}_{-1.06}$	-
			1185.6	$2^+_{\gamma-2\beta} \to 4^+_g$	-0.31(29)[d)]	-
1862.0	0.495(20)	-0.667	1517.8	$2^+_{3\beta} \to 2^+_g$	$4.69^{+2.66}_{-1.28}$ or	-
					-0.21(8)	
			543.7	$2^+_{3\beta} \to 2^+_{2\beta}$	$-3.27^{+7.76}_{-\infty}$	-
1692.4	0.774(23)	0.277(8)	1348.1	$4^+_{1\beta} \to 2^+_g$	-0.30(25) d)	-
			937.0	$4^+_{1\beta} \to 4^+_g$	-11(2)	-
1605.6	0.488(20)	-0.642(26)	1261.4	$2^+_{\beta\gamma} \to 2^+_g$	$2.59^{+2.10}_{-0.95}$	-
			675.1	$2^+_{\beta\gamma} \to 2^+_\beta$	1.84(66)	-
1550.1	0.764(22)	0.198(10)	794.7	$4^+_\gamma \to 4^+_g$	$-0.4^{+0.7}_{-1.2}$	-

Table 3 (continued)

1434.2	0.626(31)	0.216(11)	1089.9	$3^+_\gamma \to 2^+_g$	$-44 \le \delta \le -7.1$	-0.20(2)
			678.6	$3^+_\gamma \to 4^+_g$	-19(16)	$\lvert\delta\rvert > 9$ or < -14
1318.4	0.364(22)	-0.587(35)	974.1	$2^+_{2\beta} \to 2^+_g$	1.47(60)	0.58(7)
1109.2	0.413(27)	-0.349(23)	764.9	$2^+_\gamma \to 2^+_g$	$3.47^{+1.70}_{-0.91}$	4.3(7)
930.6	0.434(26)	-0.561(34)	586.3	$2^+_\beta \to 2^+_g$	-4.9(1.2)	-3.05(14)
755.4	0.316(25)	0.064(5)	411.1	$4^+_g \to 2^+_g$	0.035(195)[d)]	-

a) Level and gamma-ray transition energies were taken from Ref. /5/. b) An error in parentheses is given in units of the last decimal. c) E3 / M2 mixing ratio. d) M3 / E2 mixing ratio. e) $I_i = 1$ is preffered - see text.

the decay of the ^{152}Tb ground state ($I^{\pi} = 2^{-}$), were supposed to be of the allowed Gamov-Teller type except for those to levels with $I \geq 4$, when transitions with $\Delta L_{\beta} > 1$ had to be considered. The solid angle factors used in our calculations were $Q_2(0) = 0.986$, $Q_4(0) = 0.952$, $Q_2(\pi/2) = 0.979$, $Q_4(\pi/2) = 0.932$. They have an accuracy better than 1% for all gamma-ray energies.

3.3. Data Deduced from the Nuclear Orientation Measurements of ^{154}Tb

Study of levels populated in the decay of the ^{154}Tb nucleus is very complicated because there are three isomers of ^{154}Tb /12/ . However, some important information can be obtained from the orientation data.

The anisotropy of the 540.1 keV transition was used to determine the value of $B_2^{exp} = 0.69$ (10) assuming an E1 character for the transition and an allowed Gamov-Teller beta-transition between the $I = 3$ isomer in ^{154}Tb and the 2185.97 keV ($I^{\pi} = 4^{-}$) state in ^{154}Gd . This allowed us to deduce in a simple way the multipole E1 / M2 mixing ratios of 415.8 keV ($\delta = -0.061^{+0.012}_{-0.013}$) and 922.1 keV ($\delta = -0.023 \pm$ $\pm$ 0.166) transitions.

Using anisotropies of the 1149.1 keV, 1229.2 keV and 2153.8 keV transitions, the spin value of 3 was uniquely obtained for the 2276.9 keV state and from the measured anisotropies of 1208.1, 1965.0 and 2212.9 keV gamma transitions a spin value of 3 was deduced for the 2336.1 level. The anisotropy of the 1152.1 keV transition is consistent only with the assignment 4^{+} for the 2416.3 keV state.

Normalized intensities of transitions, from the decay of the 22.6 h ^{154}Tb isomer show that the orientation of states, populated directly or indirectly via the 2137.8 keV long-lived state ($T_{1/2} = 68$ nsec) is less than orientation of the other states. The fact is demonstrated in Table 2, where the 172.1 keV and 1061.2 keV transitions have apparently higher values of anisotropy than the other transitions (see also Fig.2 in Ref. /13/).

Nuclear orientation data can be used as an evidence of existence of a spin-zero state. As can be seen in Table 2, several of the more intense transitions, populated in the decay of 21.4 h ^{154}Tb isomer, have isotropic distributions which indicates that the isomer has $I = 0$.

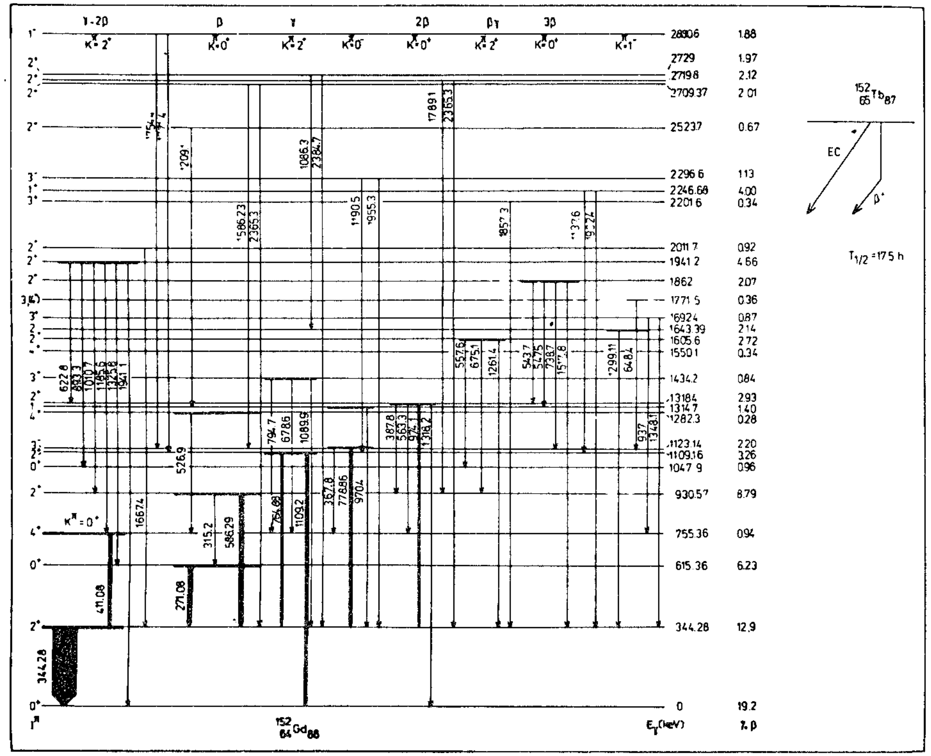

Fig.1. A fragment of the scheme of excited levels in ^{152}Gd , populated following the β^{+} and EC decay of ^{152}Tb ($T_{1/2} = 17.5$ h).

4. DISCUSSION

The doubly even nucleus ^{152}Gd (N = 88) lies in a transitional region between spherical and deformed nuclei just outside the deformed region, which begins for Gd nuclei in the N = 88-90 region /5/. The ^{152}Gd nucleus is supposed to be spherical and the ^{154}Gd nucleus is described as deformed. However, theoretical calculations of Kumar /14/ for ^{150}Sm (N=88) and ^{152}Sm (N =90) and some experimental results (see e.g. refs. /1,5,15/) indicate the possibility to interpret at least the low-lying levels of ^{152}Gd in terms of quasicollective bands. Another possibility to understand some collective features in ^{152}Gd is the idea of coexistence of deformed and spherical states in the ^{152}Gd nucleus. The conception is supported by results of

Table 4

Comparison of the experimental and theoretical E2/M1 mixing ratios for β - and γ -bands in ^{150,152,154,156}Gd.

	$^{150}_{64}Gd_{86}$ a)			$^{152}_{64}Gd_{88}$			
$I_i^\pi \to I_f^\pi$	E_γ [keV]	$\delta(E2/M1)$	δ^{th}_{HK} g)	E_γ [keV]	$\delta(E2/M1)$	δ^{th}_{RV} i)	δ^{th}_{HK}
$2^+_\beta \to 2^+_g$	880.3	$-(7^{+3}_{-1})$	- 3.2	586.3	-4.9(1.2)	- 28.4	- 2.7
$4^+_\beta \to 4^+_g$	-	-	-	526.9	-	- 0.1	- 7.6
$2^+_\gamma \to 2^+_g$	792.5	2.0(7)	8.7	764.9	$3.5^{+1.7}_{-0.9}$	- 12.1	53.6
$3^+_\gamma \to 2^+_g$	1350.4	-	3.2	1089.9	$-44 \le \delta \le -7$	- 9.8	19.9
$3^+_\gamma \to 4^+_g$	-	-	-	678.6	-19(16)	- 8.4	118.3
$4^+_\gamma \to 4^+_g$	411.7	-0.20(13)	-	794.7	$-0.4^{+0.7}_{-1.2}$	- 10.1	30.1

Table 4 (continued)

	$^{154}_{64}Gd_{90}$				$^{156}_{64}Gd_{92}$			
$I_i^\pi \to I_f^\pi$	E_γ [keV]	$\delta(E2/M1)$	δ^{th}_{RV}	δ^{th}_{HK}	E_γ [keV]	$\delta(E2/M1)$	δ^{th}_{RV}	δ^{th}_{HK}
$2^+_\beta \to 2^+_g$	692.5	$7.5^{+10}_{-2.9}$ d)	- 27.8	65.1	1040.4	$-5.9^{+1.4}_{-2.8}$ e)	- 47.8	48.4
$4^+_\beta \to 4^+_g$	676.6	$2.9^{+2.1}_{-0.9}$ b)	2.1	4.1	-	-	-	11.3
$2^+_\gamma \to 2^+_g$	873.2	- 9.7(10) c)	- 16.3	-21.2	1065.1	$-6.5^{+2.6}_{-7.9}$ f)	- 24.0	-8.2
$3^+_\gamma \to 2^+_g$	1005.0	$-6.0^{+1.1}_{-1.6}$ b)	- 16.5	-47.6	1159.0	$-11.8^{+0.6}_{-0.7}$ f)	- 19.4	-22.9
$3^+_\gamma \to 4^+_g$	756.2	-5.6(2) d)	- 12.3	-14.4	959.7	$-11.7^{+2.7}_{-5.3}$ f)	- 16.5	-37.3
$4^+_\gamma \to 4^+_g$	893.3	-4.4(6) d)	- 7.5	- 8.5	1067.2	$-4.0^{+0.9}_{-1.6}$ f)	- 13.3	13.7

a) Hamilton et al. /8/. The Sakai and Rester /17/ concept of quasi-bands was used, with an exception for the 4^+_γ level in ^{150}Gd, as was pointed out by Hamilton and Kumar /23/. b) West et al. /2/. c) Ref. /23/ and references herein. d) Whitlock et al. /24/. e) Hamilton J.H. et al. /20/. f) Uluer et al. /21/. g) Theoretical values of Kumar /14/ and Hamilton and Kumar /23/. i) Greiner /18/ model with rotation-vibration interaction.

nuclear reactions [16]. Zolnowski et al. [5] have tried to interpret the excited levels in ^{152}Gd using the concept of quasibands (Fig.1). This enables us to arrange our results in Table 3 and to compare them at least for β- and γ-bands with corresponding results for a spherical ^{150}Gd nucleus and deformed ^{154}Gd and ^{156}Gd nuclei (Table 4). The main features which can be seen in Table 3 are following:

1. Transitions between positive parity states belonging to quasicollective bands have comparatively large M1 admixtures, although forbidden by collective models. However, for low-lying levels the microscopic pairing-plus-quadrupole calculations of Kumar [22] explain the fact by the β- and γ-dependence of the gyromagnetic ratio;
2. Transitions from the high-excited levels above 2 MeV are predominantly of M1 character which probably demonstrates their single-particle nature;
3. Transitions between states of different parity have only a few tenths of percent of M2 admixture, except for the 1771.4 keV transition, depopulating the 2880.6 keV (1^-) state. Our data are consistent with the M2 + E3 multipolarity. This is in accordance with the conversion-electron data of Adam et al. [11]. Similarly, the 1754.4 keV transition from the state corresponds to the E2 + M3 multipolarity with 20^{+28}_{-16} % of M3 component. The facts might demonstrate an isometric character of the 2880.6 keV state.

An attempt has been made to compare the experimental values of multipole mixing ratios with a theoretical calculation. Unfortunately only for transitions between states of the ground, β- and γ-bands it can be done easily. For transitions $2^+_\beta \to 2^+_g$, $2^+_\gamma \to 2^+_g$ and $3^+_\gamma \to 2^+_g$ in ^{150,152,154,156}Gd the results from the dynamic deformation theory based on the Strutinsky method [23] were used. For transitions $4^+_\beta \to 4^+_g$, $3^+_\gamma \to 4^+_g$ and $4^+_\gamma \to 4^+_g$ in ^{152,154}Gd we used results of the microscopic calculations made by Kumar [14] for ^{150}Sm and ^{152}Sm, with proper energy corrections. The nuclei have the same number of neutrons as ^{152}Gd and ^{154}Gd nuclei and because of the known importance of a number of neutrons for the behaviour of a nucleus in the transitional region, such comparison is acceptable. For the transitions in ^{156}Gd the microscopic calculations based on the pairing-plus-quadrupole model have been performed by Gupta et al. [19].

Another possibility is to use the simple model of Greiner [18]. In our calculation the parameters

ϵ = 74.33 keV, E_γ = 925.5 keV, E_β = 615.3 keV, β_0 = 0.178 for ^{152}Gd,

ϵ = 32.34 keV, E_γ = 950.6 keV, E_β = 680.7 keV, β_0 = 0.279 for ^{154}Gd,

ϵ = 25.46 keV, E_γ = 1127.0 keV, E_β = 1049.6 keV, β_0 = 0.307 for ^{156}Gd

and interpolated numerical wave functions of Faessler et al. [25] were used. The results show in some cases rather good agreement with the experimental data. Nevertheless, it is necessary to point out that in general neither microscopic Kumar's calculations nor rotational-vibrational model can predict strong vibrations of δ-values in transitional nuclei. Summarizing all the results concerning mixing ratios of transitions in ^{152}Gd one can see that the ^{152}Gd nucleus is soft against deformation and at least its low-lying states can be interpreted as weakly deformed.

Spin-values, deduced from the nuclear orientation data, for states in ^{152}Gd and ^{154}Gd are difficult to interpret. The 1692.4, 1839.6 and 1915.4 keV levels have been assumed [5] to be the 4^+ member of the quasi 2β-band, the 3^+ member of the quasi $\beta\gamma$-band and the 3^- member of the $K^\pi = 1^-$ band, respectively. Our results do not confirm the assumption.

5. CONCLUSIONS

The nuclear orientation data has been used to elucidate the nature of the transitional ^{152}Gd nucleus. Detailed analysis of deduced multipole mixing ratios supports the interpretation of ^{152}Gd as of a weakly deformed nucleus. No data contradicting the existence of three-phonon states [5] in ^{152}Gd have been found. The comparison of theoretical and experimental data shows a limited application of the dynamical deformation theory based on the pairing-plus-quadrupole model or based on the Strutinsky method and the rotational-vibrational model for interpretation of multipole mixing ratios in transitional nuclei.

The spin-value of 0 for the 21.4 h isomer in ^{154}Gd was verified and an influence of the 2137.8 keV ($T_{1/2}$ = 68 ns) state on the orientation of lower-lying states, populating via the state, was observed.

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