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Multipole mixing ratios of transitions in ^{156}Gd

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Abstract. Using γ–$\gamma(\theta)$, and e_K–$\gamma(\theta)$ directional correlation and $\gamma(\theta)$ (nuclear orientation) techniques we have determined the multipole character of twenty one transitions occurring in ^{156}Gd following the decay of ^{156}Tb. For the γ–γ directional correlation measurements a good energy resolution system employing a Ge(Li) and a NaI(Tl) detector was used while for the e_K–γ correlations we used a NaI(Tl) detector and a magnetic lens spectrometer. The nuclear orientation measurements were carried out at low temperatures obtained with a ^{3}He–^{4}He dilution refrigerator to which an adiabatic stage was attached.

The observed mixing ratios show that the transitions de-exciting the γ band and the 5^+ and 4^+ rotational levels are predominantly E2, and that the γ rays originating from the 3^- and 4^- rotational levels are predominantly E1. The 4^+_{rot}–6^+_{gr}, 4^+_{rot}–2^+_{gr}, 4^+_{rot}–2^+_{γ} transitions de-exciting the 1510·7 keV ($K = 4$) level are shown to have M3 admixtures. The signs and magnitudes of the multipole mixing ratios of the 2_γ–2_{gr}, 3_γ–2_{gr}, 3_γ–4_{gr}, and 4_γ–4_{gr} transitions are consistent with the tabulated values of the other even–even nuclei in this region.

RADIOACTIVITY Tb^{156} (from Gd(p : xn) chem.); measured $\gamma\gamma(\theta)$, $e_K\gamma(\theta)\,\gamma(\theta)$. ^{156}Gd transitions deduced E2 : M1, M2 : E1, M3 : E2 mixing ratios. Natural targets, mass-separated source, polarized nuclei; Ge(Li), NaI(Tl) detectors, magnetic spectrometer.

1. Introduction

The nucleus ^{156}Gd is situated at the onset of the deformed region and is one of the first nuclei to show the well developed γ-vibrational bands which characterize the region; the β-band which is strongly excited in the transitional ^{152}Gd, and moderately excited in ^{154}Gd nuclei, plays a relatively minor role in the decay of ^{156}Tb. The level structure of ^{156}Gd following the β^+ and EC decay of ^{156}Tb ($T_{1/2}$ = 5·4d) has been investigated recently by Kenealy *et al* (1967), Fujoka (1970) and McMillan *et al* (1971). One of the special features of this which also appears in three other nuclei, namely ^{160}Dy, ^{172}Yb and ^{190}Os, is the $K^\pi = 4^+$ band to which the 1510·7 and 1622·6 keV levels are assigned in ^{156}Gd. However, this assignment requires confirmation, and more precise information about the multipolarities of the transitions linking these levels to the other states.

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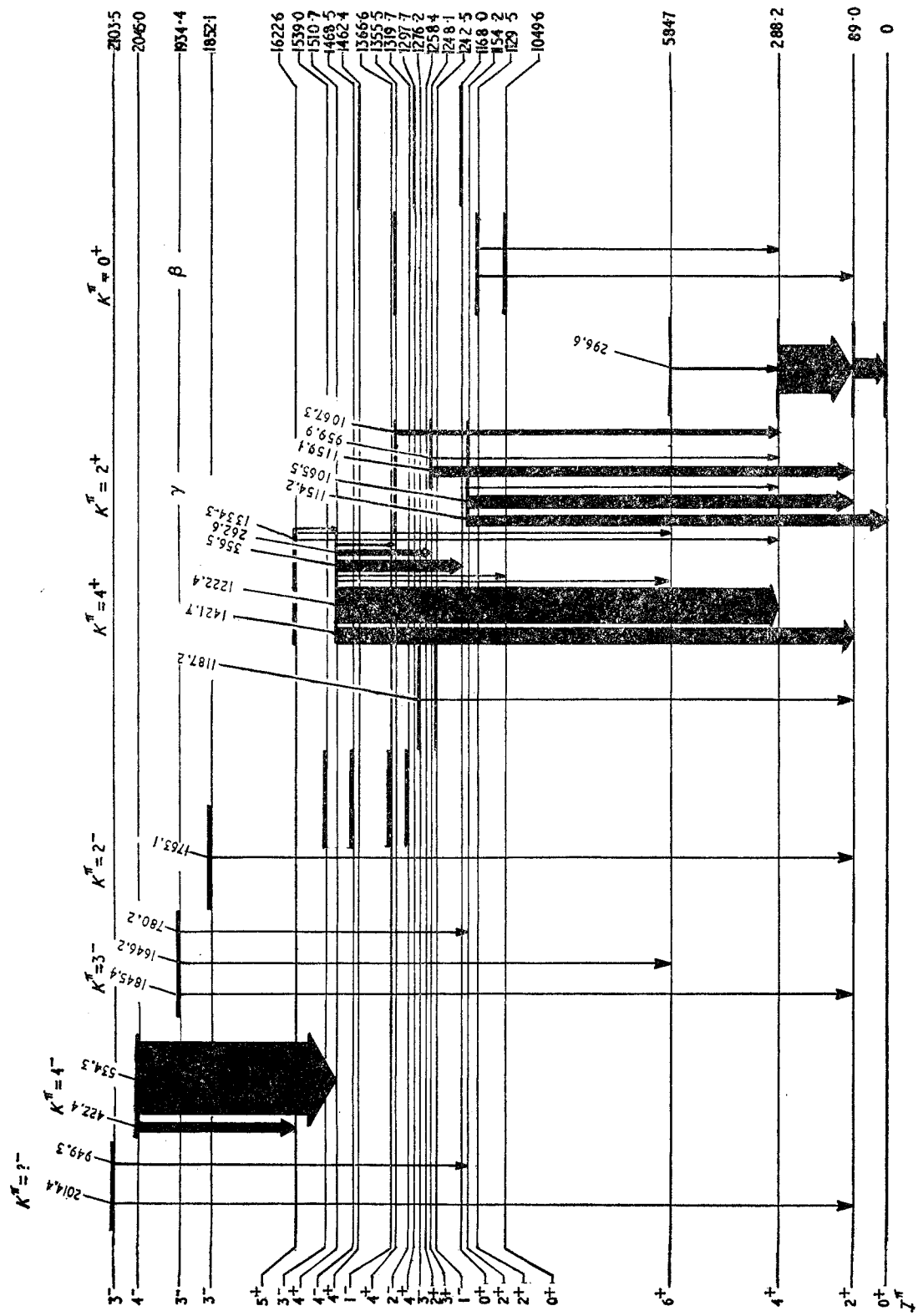

Figure 1. A simplified version of the level structure of ^{156}Gd populated following the β^+ and EC decay of ^{156}Tb ($T_{1/2} = 5{\cdot}4$d).

Figure 1 shows a simplified version of the level scheme and although this is established quite well, little work has been done regarding multipolarity determination of the various transitions. Such information would be useful in establishing the nature of the ^{156}Gd level structure and would serve as a basis for comparison with the relevant model predictions. The pairing plus quadrupole interaction as developed by Kumar (1974) has been particularly successful when applied to nuclei at each end of the deformed region and it would be interesting to apply it to a well deformed nucleus.

The aim of the present work is to determine the mixing ratios of transitions in ^{156}Gd which occur following the β^+ and EC decay of ^{156}Tb. The complementary techniques of the directional correlation of cascade γ rays and the directional distribution of γ rays emitted by oriented nuclei have been used.

2. Source preparation

The ^{156}Tb activity was produced at the Dubna synchrocyclotron. A gadolinium target was bombarded with 120 MeV protons and the terbium activity was obtained using ion exchange methods. The ^{156}Tb was selected by mass separation. The mass separator operated at 25 kV and produced the activity as a strip approximately 6 mm long by 1·5 mm wide on a 25 μm aluminium foil. A piece of this was rolled in the form of a point source and enclosed in a polythelene vial and used in the γ–γ directional correlation measurements. For the electron–gamma directional correlations a $1{\cdot}5 \times 1{\cdot}5\ \text{mm}^2$ source was used.

For the nuclear orientation experiments samples were prepared by implanting radioactive ^{156}Tb atoms into a foil of 99·9% gadolinium at a potential of 70 kV. These samples were melted onto a tantalum boat in an atmosphere of pure argon which was continuously flowing. The gadolinium wets the tantalum surface so that good thermal contact should be achieved. The tantalum boat was then hard soldered directly onto the thermal link of a chrome alum salt pill. The hard solder was copper–silver eutectic with a powder of copper oxide and titanium oxide used as flux. A sample of ^{54}Mn dissolved in iron was soldered beside the ^{156}Tb sample to provide a measure of the sample temperature.

The salt pill was made by imbedding 10 000 strands of 48 gauge copper wire in a slug of chrome alum and glycerol. At one end of the salt pill the wires were drawn together and bonded with epoxy resin. This formed a thermal link to which the radioactive samples were soldered.

3. Experimental methods

3.1. Gamma–gamma directional correlations

A 30 cm^3 Ge(Li) detector with a resolution of 2·3 keV at 1·33 MeV and a $7{\cdot}6 \times 7{\cdot}6$ cm NaI(Tl) crystal were used. The Ge(Li) detector was used as the stationary one to record the gamma ray spectrum that was in coincidence with a transition selected by a gate set on the NaI(Tl) detector spectrum. Four angles were chosen for the NaI(Tl) detector which moved around the source at regular time intervals. These intervals were short enough to minimize any count rate fluctuations due to electronic drifts and the effect of source decay. The data were stored in four quadrants of a 4096 channel analyser. The

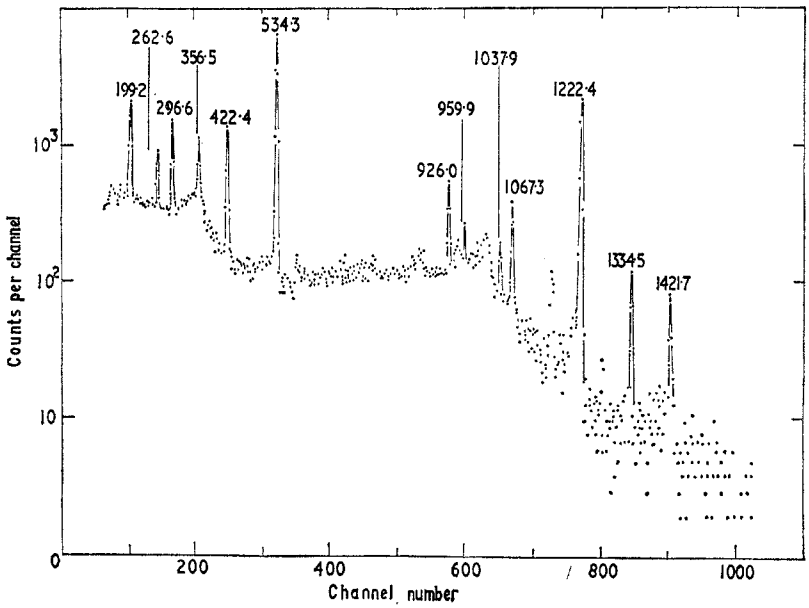

Figure 2. A typical ^{156}Gd gamma ray spectrum gated with the 199·2 keV transition, from which accidentals have been subtracted. Transition energies are given in keV.

source was centred to an accuracy of better than 1·5%. The resolving time was 50 ns and the true to accidental ratio was always better than 50 : 1.

The accidental coincidences were subtracted automatically and the contribution due to the background was also determined and subtracted from the data. The gamma ray spectrum recorded by the Ge(Li) detector when the gate on the NaI(Tl) spectrum was set on the 199·2 keV transition is shown in figure 2.

A computer program was used to determine the least squares fit of the data to the directional correlation function given by

$$W(\theta) = \sum_{\lambda \text{ even}} B_\lambda(\gamma_1) A_\lambda(\gamma_2) Q_\lambda(\gamma_1) Q_\lambda(\gamma_2) P_\lambda(\cos\theta) \tag{1}$$

where the directional correlational coefficients are given by

$$B_\lambda(\gamma_1) = [F_\lambda(LLI'I) - 2\delta F_\lambda(LL'I'I) + \delta^2 F_\lambda(L'L'I'I)](1+\delta^2)^{-1} \tag{2}$$

and

$$A_\lambda(\gamma_2) = [F_\lambda(LLI'I) + 2\delta F_\lambda(LL'I'I) + \delta^2 F_\lambda(L'L'I'I)](1+\delta^2)^{-1}. \tag{3}$$

F_λ are the angular momentum coupling factors. These coefficients are normalized so that $B_0 = 1 = A_0$. Here $L' = L+1$ and δ is the amplitude ratio of $L+1$ to L multipole components; the convention for the sign of δ being that of Krane and Steffen (1970). In those cases when an intermediate transition occurs in a cascade it is necessary to include a de-orientation coefficient U_λ in the product of coefficients in equation (1).

3.2. Electron–gamma directional correlations

Internal conversion electrons were detected by a magnetic lens spectrometer which was

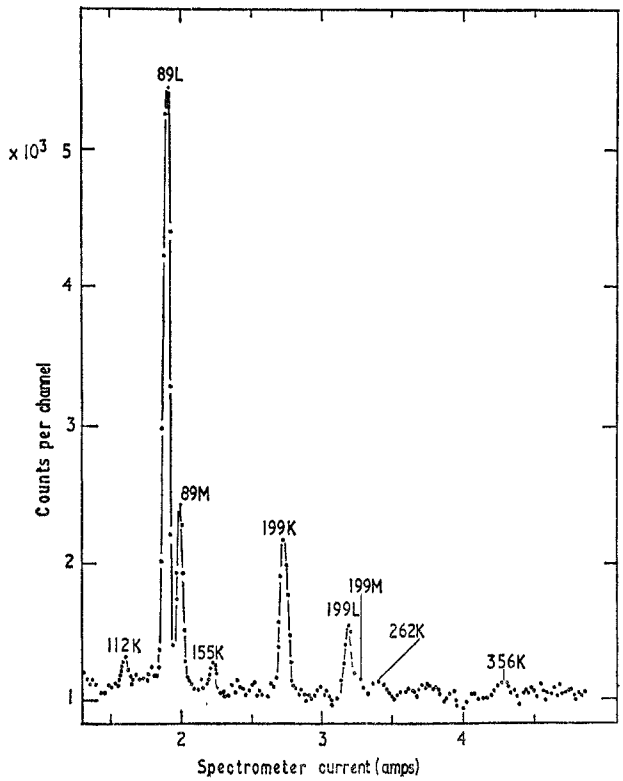

Figure 3. The low energy part of ^{156}Gd conversion electron spectrum. Electron lines are marked with the corresponding gamma ray energy (in keV) and the electron shell.

set at an energy resolution of 0·8% (FWHM). A typical electron spectrum is shown in figure 3.

Again a 7·6 × 7·6 cm NaI(Tl) crystal was used as a moving detector for the coincidence spectrum. Accidental coincidences were subtracted automatically, and the data, obtained at four angles, was stored in the four quadrants of a 400 channel analyser. The resolving time was 50 ns and the true to accidentals ratio was of the order of 100 : 1. The source was centred to within 1·5%. The data were analysed in the same way as in $\gamma\gamma$ correlations, except that the angular correlation function has a factor b_λ^K included which is the particle parameter for the detected K-shell internal conversion electron.

3.3. Nuclear orientation

The prepared salt pill was suspended beneath a ^{3}He–^{4}He dilution refrigerator operating at 30 mK, to which it was thermally linked by a lead heat switch. After demagnetizing the salt pill, a small polarizing field of 6 kgauss was used to align the magnetic domains of the gadolinium and iron.

The gamma ray count rate was taken at angles of 0 and $\pi/2$ with respect to the applied field direction, using a 30 cm^3 Ge(Li) detector. The voltage pulses were amplified and fed into a 4096 channel analyser. The full energy spectrum was read onto magnetic tape every 1000 or 2000 seconds. Computer analysis of the spectrum involved summing

the counts in the channels across each peak and subtracting the background radiation from under it. The latter was obtained by fitting a straight line to channels on each side of the peak and calculating the trapezoidal area beneath the peak formed by joining the end points of the fitted backgrounds. A correction for source decay was also made.

The directional distribution of radiation obtained from the polarized sample is given by

$$W(\theta) = \sum_{\lambda \text{ even}} B_\lambda(I) A_\lambda(\gamma) Q_\lambda(\gamma) U_\lambda P_\lambda(\cos\theta) \tag{4}$$

where the orientation coefficients $B_\lambda(I)$ contain dependence on the equilibrium nuclear level populations and are functions of temperature. The rest of the parameters are similar to those which appear in the directional correlation function.

The anisotropies $1-W(0)$ and $W(\pi/2)-1$ were obtained by comparing the cold counts with the warm (1K) counts for which the distribution of radiation is isotropic. The results of several experimental runs were averaged. The average temperature, as measured by the ^{54}Mn in iron thermometer, was 10·4(2) mK.

4. Results

4.1. Directional correlations

Spectra were obtained in coincidence with 89·0, 199·2 and 356·5 keV gamma rays and also 199·2 and 356·5 keV K shell conversion electrons. It is useful to comment on some points that were considered in the evaluation of the data.

No attenuation of the correlation patterns was expected in the measurements since apart from the 89·0 keV level ($T_{1/2}$ = 2·1 ns) the half lives of the other states are expected to be less than 10^{-10} s (only the 1510·5 and 288·2 keV states have measurable half lives of 0·19 and 0·12 ns respectively). In order to confirm that this assumption is valid several 4^+–2^+–0 correlations were measured, since for these there is no uncertainty in the expected values of the correlation coefficients. These experimental results were consistent with the theoretical values.

The mixing ratio of the 534·3 keV transition was measured in two ways: the 4^- (534·3 keV gamma) 4^+ (356·5 keV K electron) 2^+ correlation gave $\delta = 0{\cdot}05 \pm 0{\cdot}04$ and the 4^- (534·3 keV) 4^+ (1222·4 keV etc) 4^+ (199·2 keV) 2^+ gamma–gamma correlation gave $\delta = 0{\cdot}07 \pm 0{\cdot}03$. The results from the average of the B_2 coefficients is $\delta = 0{\cdot}06 \pm 0{\cdot}02$. The mixing ratio of the 262·2 keV was found from the 4^+ (262·6 keV) 3^+ (1159·1 and 959·9 + 199·2 keV) 2^+ (89·0 keV) 0^+ correlation. The de-orientation parameter for the unobserved intermediate transitions was derived using the mixing ratios from the more accurate nuclear orientation measurements for the 1159·1 and 959 keV transitions and the relative intensities obtained by McMillan (1971). The result was $U_2 = 0{\cdot}17(1)$.

The mixing ratio of the 1222 keV transition was obtained from both gamma–gamma and electron–gamma correlation measurements with the 199·2 keV transition. In order to evaluate the latter it is necessary to know the particle parameter accurately. This may be taken as the theoretical value $b_2^K = 1{\cdot}785$ from Hager and Seltzer (1968), but in view of inconsistencies between theoretical and experimentally determined values, (Kalfas *et al* 1973) it is perhaps best to measure the b_2^K value. This was done by comparing the 534·3–199·2 keV gamma–gamma and gamma–electron correlations. This comparison yields b_4^K aud from the recursion relationship, $b_2^K = 1{\cdot}4 - 0{\cdot}4\, b_4^K$, one obtains $b_2^K = 1{\cdot}82(25)$. These consistent results may be averaged and give

Table 1. Results of gamma–gamma and electron–gamma directional correlation measurements.

Transition			Correlation coefficients		Mixing ratio
Initial level (keV)	Energy (keV)	Spin parity $I_i^{\pi}-I_f^{\pi}$	$B_2 A_2$	$B_4 A_4$	(E2/M1) or (M2/E1)
2045	534	4^-–4^+	0·110(7)[b]†	0·016(16)	$0{\cdot}07\pm0{\cdot}03$
			0·287(20)[d]†	0·078(53)	$0{\cdot}05\pm0{\cdot}04$
1852	1763	3^-–2^+	−0·050(164)[a]	0·028(458)	$0{\cdot}16^{+0{\cdot}33}_{-0{\cdot}22}$
1623	1335	5^+–4^+	−0·331(51)[b]	0·45(123)	$-2{\cdot}89^{+0{\cdot}82}_{-1{\cdot}22}$
	1038	5^+–6^+	0·092(76)[b]†	0·152(176)	$-6{\cdot}7^{+}_{-21{\cdot}0}{}^{3{\cdot}0}$
	112	5^+–4^+	0·026(56)[c]	0·235(185)	$0{\cdot}15^{+0{\cdot}10}_{-0{\cdot}09}$
1511	1222	4^+–4^+	0·053(15)[b]	0·126(35)	$-2{\cdot}07^{+0{\cdot}13}_{-0{\cdot}14}$
			0·117(28)[e]	−0·134(71)	
	263	4^+–3^+	−0·006(27)[a]†	0·033(53)	$5{\cdot}2^{+}_{-}{}^{8{\cdot}7}_{2{\cdot}1}$
1356	1067	4^+–4^+	−0·030(27)[b]	0·134(64)	$-4{\cdot}0^{+}_{-}{}^{0{\cdot}9}_{1{\cdot}6}$
1248	960	3^+–4^+	0·088(39)	−0·064(90)	$-12{\cdot}5^{+}_{-22{\cdot}0}{}^{4{\cdot}0}$
1154	1066	2^+–2^+	−0·022(46)[c]	0·16(14)	$\lvert\delta\rvert\geqslant4$

† These measured correlation coefficients include a contribution due to an intermediate transition and the appropriate U_λ must be evaluated to allow δ to be determined.

[a] In coincidence with 89·0 keV.
[b] In coincidence with 199·2 keV.
[c] In coincidence with 356·5 keV.
[d] In coincidence with 356·5 keV K-electron.
[e] In coincidence with 199·2 keV K-electron.

$b_2^{K} = 1{\cdot}81(15)$, and if this is used in the evaluation of the 1222·4–199·2 keV gamma–electron data one obtains $\delta(1222{\cdot}4) = -2{\cdot}00^{+0{\cdot}18}_{-0{\cdot}20}$ which is in excellent agreement with the gamma–gamma result; $-2{\cdot}14^{+0{\cdot}18}_{-0{\cdot}21}$. It may also be noted that the theoretical and experimental b_2^{K} values are in good agreement. The directional correlation results are given in table 1.

4.2. Nuclear orientation results

Table 2 contains the values of the measured anisotropies obtained at 0 and $\pi/2$ with respect to the applied field direction. Accurate measurements were possible for twenty γ rays occurring in ^{156}Gd. From these anisotropies the product $B_\lambda U_\lambda A_\lambda Q_\lambda$ was derived using the relationships

$$B_2 U_2 A_2 Q_2 = -\tfrac{8}{7}\{[W(\pi/2)-1]+\tfrac{3}{8}[1-W(0)]\} \tag{5}$$

and

$$B_4 U_4 A_4 Q_4 = \tfrac{4}{7}\{2[W(\pi/2)-1]-[1-W(0)]\}. \tag{6}$$

The solid angle factors, with the Ge(Li) detector separated from the source by 9 cm are

Table 2. Measured anisotropies in the nuclear orientation experiments.

Energy keV	$1-W(0)$	$W(\pi/2)-1$	$B_2 U_2 A_2 Q_2$	$B_4 U_4 A_4 Q_4$
199	0·200(2)	0·105(3)	0·206(4)	0·006(5)
263	0·128(3)	0·093(7)	−0·161(8)	0·033(8)
297	0·251(3)	0·132(8)	−0·258(9)	0·007(9)
356	0·318(3)	0·150(4)	−0·308(5)	−0·010(5)
422	−0·137(3)	−0·054(5)	0·120(6)	0·017(6)
534	0·363(2)	0·188(3)	−0·370(4)	0·007(4)
780	−0·254(7)	−0·125(16)	0·252(18)	0·002(18)
926	0·101(4)	0·061(12)	−0·113(14)	0·012(14)
949	−0·261(13)	−0·064(31)	0·185(35)	0·076(35)
960	−0·076(11)	−0·037(26)	0·075(30)	0·001(30)
1065	−0·130(40)	−0·050(30)	0·110(40)	0·017(40)
1154	0·309(3)	0·129(5)	−0·280(6)	−0·029(6)
1159	−0·013(3)	−0·020(8)	0·028(9)	−0·015(9)
1187	−0·263(21)	−0·173(53)	0·310(60)	−0·047(60)
1222	−0·258(2)	−0·138(3)	0·268(4)	−0·010(5)
1335	−0·430(5)	−0·143(10)	0·348(12)	0·082(12)
1422	0·319(3)	0·148(5)	−0·306(6)	−0·013(6)
1646	−0·105(3)	−0·041(9)	0·092(11)	0·013(11)
1845	−0·261(3)	−0·122(8)	0·251(9)	0·010(9)
2014	−0·240(7)	−0·121(15)	0·241(17)	−0·001(7)

$Q_2 = 0{\cdot}980$ and $Q_4 = 0{\cdot}830$. These have an accuracy of better than 0·5% for all γ ray energies. The anisotropy of the 534 keV transition is used to derive a value for $B_2(I)$ by taking $\delta(534) = 0{\cdot}06(2)$ and $U_2 = 0{\cdot}905$ and $U_4 = 0{\cdot}681$ for the allowed 3^-–4^- Gamow–Teller β decay to the 2045 keV level. This yields $B_2 = 0{\cdot}88(2)$, which is used to analyse all other γ ray transitions.

The 356 and 1422 keV transitions from the 1511 keV level are both 4^+–2^+ transitions. Since their measured anisotropies are identical so also must be their values of the $B_2 U_2 A_2 Q_2$ term. In order to evaluate this, so that A_2 may be found, the U_2 coefficient must be determined, and taking account of the 534 keV transition and the 422–112 keV cascade to the 1511 keV level then $U_2 = 0{\cdot}770(3)$, also $U_4 = 0{\cdot}34(1)$. The evaluation yields $A_2 = -0{\cdot}642(12)$ and this requires a small M3 contribution in each transition corresponding to $\delta = 0{\cdot}014(12)$. From the A_2 coefficient it is possible to derive the A_4 co-efficient, $A_4 = -0{\cdot}28(2)$ and from this one obtains $B_4 = 0{\cdot}12(4)$. This value of B_4 is used to analyse all subsequent transitions. The values of B_2 and B_4 for ^{156}Tb dissolved in gadolinium should be calculable from the known magnetic quadrupole moments of ^{156}Tb and the resonance measurements on ^{159}Tb in gadolinium performed by Kobayashi *et al* (1967). Unfortunately, the measurements do not agree with these predictions as has already been observed for ^{160}Tb in gadolinium (Fox *et al* 1974). The source of this discrepancy is still not clear, although the value of B_4 in the present measurements indicates that it does not arise due to poor solubility of terbium in gadolinium. If this were the case, a value of $B_4 = 0{\cdot}35$ would be expected at the temperature of the experiment.

The analysis of all other γ ray transitions is based upon the values of B_2 and B_4 measured above and values of U_2 and U_4 as tabulated in table 3. These have been derived on the basis that allowed β transitions should be pure Gamow–Teller and by accepting the intensities quoted by McMillan *et al* (1971). For the 148 keV level the

Table 3. The results of the nuclear orientation experiments.

				Values derived directly from table 2		Values derived using a calculated $B_4U_4A_4Q_4$	
Level keV	Transition keV	U_2	U_4	A_2	δ E2/M1 or M2/E1	A_2	δ E2/M1 or M2/E1†
2103	2014	0·750	0·167	0·37(3)	−0·01(1)	0·371(14)	−0·013(7)†
	949	0·750	0·167	0·29(6)	+0·03(3)	0·39(2)	−0·025(12)†
2045	422	0·905	0·681	0·154(8)	−0·004(6)	0·173(6)	0·009(4)†
1934	1845	0·750	0·167	0·39(2)	−0·022(9)	0·040(1)	−0·030(5)†
	1646	0·750	0·167	0·14(2)	−0·002(12)	0·161(6)	0·012(4)†
	780	0·750	0·167	0·39(3)	−0·023(15)	0·39(1)	−0·024(8)†
1622	1335	0·850	0·544	0·48(2)	−3·8(2)	0·54(3)	−3·3(2)
1511	1222	0·770(3)	0·34(1)	0·403(11)	$-2{\cdot}5^{+0{\cdot}5}_{-0{\cdot}8}$	0·413(12)	(*a*)
	263	0·770(3)	0·34(1)	−242(13)	$9{\cdot}2^{+0{\cdot}7}_{-0{\cdot}6}$	−0·227(13)	$10{\cdot}00^{+0{\cdot}8}_{-0{\cdot}7}$
1276	1187	0·62(5)	0·10(2)	0·58(12)	−0·13(7)	0·49(6)	−0·08(3)†
1248	1159	0·48(6)	−0·04(28)	0·07(2)	$10{\cdot}0^{+100}_{-1{\cdot}4}$	0·039(9)	$-11{\cdot}8^{+0{\cdot}6}_{-0{\cdot}7}$
	960	0·48(6)	−0·04(28)	0·18(8)	-11^{+4}_{-17}	0·19(4)	$-11{\cdot}7^{+2{\cdot}7}_{-5{\cdot}3}$
1154	1065	0·54(2)	0·24(9)	0·24(9)	-10^{+5}_{-45}	0·30(9)	$-\ 6{\cdot}5^{+2{\cdot}6}_{-7{\cdot}9}$
					M3/E2		M3/E2
1511	1422	0·770(3)	0·34(1)	−0·642(12)	0·014(12)		
	356	0·770(3)	0·34(1)	−0·642(12)	0·014(12)		
	926	0·770(3)	0·34(1)	−0·170(21)	0·05(2)	−0·149(7)	0·068(6)

(*a*) The maximum value that A_2 may have in a mixed multipole 4^+–4^+ transition is $A_2 = 0{\cdot}3875$ which corresponds to $\delta = -2{\cdot}38$.

β decay was permitted to transfer 0, 1 or 2 units of angular momentum, the error on U_2 and U_4 being adjusted to cover all possibilities. For the 1154 keV level the anisotropy of the pure E2, 1154 keV γ ray was used to derive values of U_2 and U_4.

Table 3 contains the values of A_2 and δ derived for each transition based on the values of $B_2 U_2 A_2 Q_2$ given in table 2. Since the values of $B_4 U_4 A_4 Q_4$ are small it is possible to calculate these fourth order terms from the above measured mixing ratios. These new values of $B_4 U_4 A_4 Q_4$ then enable the second order terms to be derived solely from the measurement at $\theta = 0$. In cases where the fourth order term is very small, this method of analysis greatly decreases the error, most of which arises from the inaccuracy of the $\pi/2$ measurements. Values of A_2 and δ calculated in this manner are also given in table 3. In most cases there is good agreement between these two methods of analysis.

5. Discussion

The results of the nuclear orientation measurements are, for the most part, more precise

Table 4. E2/M1, M2/E1, M3/E2 mixing ratios of various transitions in ^{156}Gd.

Initial level (keV)	Transition (keV)	J^π	$J'^{\pi'}$	Mixing ratio (δ)			
				Present work		Previous measurements	
				E2/M1	M2/E1	E2/M1	M2/E1
1154·2	1065·5	2^+_γ	2^+_{gr}	$-6{\cdot}5^{+2{\cdot}6}_{-7{\cdot}9}$		$-18(3)^a$	
1248·4	959·9	3^+_γ	4^+_{gr}	$-11{\cdot}7^{+2{\cdot}7}_{-5{\cdot}3}$		$0{\cdot}26 \leqslant \delta \leqslant 7{\cdot}44^b$	
	1159·1	3^+_γ	2^+_{gr}	$-11{\cdot}8^{+0{\cdot}6}_{-0{\cdot}7}$		$-8{\cdot}5^{+4{\cdot}1^b}_{-61{\cdot}9}$	
1276·2	1187·2	3^-_{oct}	2^+_{gr}		$-0{\cdot}08(3)$		
1355·5	1067·3	4^+_γ	4^+_{gr}	$-4{\cdot}0^{+0{\cdot}9}_{-1{\cdot}6}$			
1510·7	262·6	4^+_{rot}	3^+_γ	$9{\cdot}2^{+0{\cdot}7}_{-0{\cdot}6}$			
	1222·4	4^+_{rot}	4^+_{gr}	$-2{\cdot}07^{+0{\cdot}13}_{-0{\cdot}14}$		$-2{\cdot}12^{+0{\cdot}37^b}_{-0{\cdot}41}$	
1622·6	111·9	5^+_{rot}	4^+_{rot}	$0{\cdot}15^{+0{\cdot}10}_{-0{\cdot}09}$		$\lvert\delta\rvert = 0{\cdot}089 \pm 0{\cdot}003^c$	
	1037·9	5^+_{rot}	6^+_{gr}	$-6{\cdot}7^{+3{\cdot}0}_{-21{\cdot}0}$			
	1334·5	5^+_{rot}	4^+_{gr}	$-3{\cdot}8(2)$		$-3{\cdot}44^{+1{\cdot}27^b}_{-2{\cdot}58}$	
1852·1	1763·1	3^-_{rot}	2^+_{gr}		$0{\cdot}16^{+0{\cdot}33}_{-0{\cdot}22}$		
1934·4	780·2	3^-_{rot}	2^+_γ		$-0{\cdot}024(8)$		
	1646·2	3^-_{rot}	4^+_{gr}		$0{\cdot}012(4)$		$-0{\cdot}002^{+0{\cdot}063^b}_{-0{\cdot}078}$
	1845·4	3^-_{rot}	2^+_{gr}		$-0{\cdot}030(5)$		$-0{\cdot}024^{+0{\cdot}134^b}_{-0{\cdot}126}$
2045·0	422·4	4^-_{rot}	5^+_{rot}		$-0{\cdot}009(4)$		
	534·3	4^-_{rot}	4^-_{rot}		$0{\cdot}06(2)$		$0{\cdot}03^{+0{\cdot}13^b}_{-0{\cdot}15}$
2103·5	949·3	3^-_{rot}	2^+_γ		$-0{\cdot}025(12)$		
	2014·4	3^-_{rot}	2^+_{gr}		$-0{\cdot}013(7)$		
					M3/E2		
1510·7	926·0	4^+_{rot}	6^+_{gr}		$0{\cdot}068(6)$		
	1421·7	4^+_{rot}	2^+_{gr}		$0{\cdot}014(12)$		
	356·5	4^+_{rot}	2^+_γ				

[a] Hamilton *et al* (1972).
[b] Kenealy *et al* (1967).
[c] Fujoka (1970).

than the directional correlation experiments; however there is good agreement between the two independent sets of data which indicates their accuracy. The selected results obtained from both measurements are listed in table 4 together with the results obtained in previous work; these latter results have been chosen so that only those with the smallest error are listed. It may be seen that there is good consistency between the two sets of data where a comparison is possible. The present results besides being more extensive are also significantly more accurate with the one exception being the result of Fujioka (1971) for the 111·9 keV transition obtained from ratios of L-subshell conversion electrons.

In general the group of E1 transitions have rather small M2 admixtures. Except for the 534 keV which has a positive δ, the negative sign is dominant for the E1 transitions.

The transitions from the 1511 keV $K^\pi = 4^+$ level are interesting in that they show a large M1 admixture in the 1222 keV, 4^+–4^+ transition, and a quite definite, although small, M3 admixture in the 926 keV 4^+–6^+ transition. Attempts to explain the anisotropy of the 1222 keV transition by allowing an M3 rather than M1 admixture cause the directional distribution and γ–γ correlation measurements to be in marked disagreement. Consequently we believe the large M1 admixture to be correct. Furthermore, despite the smallness of the M3 admixture in the 926 keV transition the experimental results rule out the possibility that this transition is pure E2 radiation. This would require that the anisotropy of the 926 keV gamma ray was equal to 0·15 which is 50% larger than the observed value of $0{\cdot}101 \pm 0{\cdot}004$.

The 112 keV gamma ray between the 5^+ and 4^+ rotational states is predominantly M1 as suggested by ICC measurements.

It is noticeable that the sign of δ is negative for transitions between the $K^\pi = 4^+$ band and members of the ground state band. Similarly transitions between the $K^\pi = 2^+$ band and the ground state band have negative mixing ratios. The sign of δ for the 263 keV transition from the $K^\pi = 4^+$ band to the quasi vibrational band is positive.

The M3 : E2 mixing ratios of transitions originating from the 1511 keV level have positive signs. The signs and the magnitudes of 2_γ–2_{gr}, 3_γ–2_{gr}, 3_γ–4_{gr}, 4_γ–4_{gr} mixing ratios fit well in the tabulation of Krane (1973), which has mixing ratios for the even nuclei in the deformed region.

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