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ANGULAR CORRELATION AND LIFETIME MEASUREMENTS IN ^{154}Gd

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Multipole admixtures in 591.80, 692.51, 723.38, 756.84, 873.27, 1004.74, 1274.50, 1494.22 and 1596.65 keV transitions have been measured by investigating nine gamma-gamma angular correlations in ^{154}Gd. The present study confirms very small Ml admixtures in the transitions from β- and γ-vibrational bands to ground state band in ^{154}Gd which is a transitional nucleus. In addition, lifetime of an excited level at 123.04 keV has been measured to be 1.19 ± 0.03 nsec.

Keywords : Angular Correlation; ^{154}Gd; Multipole Admixtures; Radioactive Decay; β- and γ-Vibrational Bands

INTRODUCTION

THE radioisotope ^{154}Eu decays to ^{154}Gd by beta emission with a half life of 8.8 years. Being a transitional nucleus, a considerable interest has been focussed, both experimentally and theoretically, on the study of ^{154}Gd nucleus (Göttel *et al.*, 1972; Meyer, 1968; Mottelson, 1968; Riedinger *et al.*, 1970; Rud & Bonde Nielson, 1970; Vernell *et al.*, 1969; Whitlock *et al.*, 1971; Gupta *et al.*, 1977; and Harmatz, 1979). On the basis of theoretical calculations, Mottelson (1968) has shown large Ml admixtures in $2^+_\beta - 2^+_g$ and $2^+_\gamma - 2^+_g$ transitions in transitional nuclei such as ^{154}Gd in order to explain the branching ratios from the β- and γ-bands in this nucleus. But various experimental results show very small Ml admixtures in these transitions, which is a serious controversial aspect in this nucleus. In case of 1004.74keV transition, the experimental value of multipolarity quoted by almost all the earlier research workers is E2 with small admixture of Ml but Rud and Bonde Nielson (1970) has shown large Ml component in this transition.

The lifetime of 123.04 keV level in ^{154}Gd has already been measured by many research workers (Lederer & Shirley, 1978) but the existing values vary from 1.15 to 1.21nsec having an uncertainty of the order of 0.04nsec. However, the recently compiled data (Lederer & Shirley, 1978) shows 1.17nsec which is, perhaps, the average value of all the existing results.

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In order to check the Ml admixtures in $2_{\beta}^{+}-2_{g}^{+}$ and $2_{\gamma}^{+}-2_{g}^{+}$ transitions, and remeasure the lifetime of the 123.04keV level in ^{151}Gd, it was thought worthwhile to carry out angular correlation and lifetime measurements, in the decay of ^{154}Eu, by using experimental set-ups of good time resolution.

EXPERIMENTAL SET-UP AND DATA ANALYSIS

Gamma-gamma angular correlation measurements were performed by using a fast coincidence set-up involving 64.1cc Ge(Li) and 3″ × 3″ NaI(Tl) detectors alongwith a time-to-pulse height converter and constant fraction discriminators. The time resolution of the spectrometer was $\sim$ 8nsec. The source was placed at distances of 10 and 14cm from Ge(Li) and NaI(Tl) detectors respectively. The data were recorded at 7 angles by rotating the NaI (Tl) detector relative to the fixed Ge (Li) detector from 180° to 90° with a variation of 15°.

The angular correlations were studied by selecting a gate at 123.04keV peak on single channel analyser set to receive pulses from NaI(Tl) detector and the Ge(Li) spectra in coincidence with this gated transition was recorded on a 4096 channel analyser (ND 100). The chance coincidences were also recorded by shifting the gate of the single channel analyser connected to the output of time-to-pulse height converter from coincidence peak region to chance region of the time spectrum. In order to correct for the effects of Compton appearing in the 123.04keV peak, an angular correlation was also run by setting the window of single channel analyser at Compton region above 123.04keV peak, while all other conditions were kept the same. The least square fitting method of Rose (1953) was used to obtain the correlation coefficients A_2 and A_4. Solid angle corrections were made using correction factors calculated by Yates (1965) for the NaI (Tl) detector and by Camp and Vanlehn (1969) for the Ge(Li) detector. The method of Arns and Wiedenbeck (1958) was used for calculating the multipole admixtures in various transitions in ^{154}Eu decay.

The lifetime of the 123.04keV excited state in ^{154}Gd has been measured using two plastic detectors (NE102, 1″ × 1″) in a coincidence set-up. The time resolution of the set-up was measured to be 800 psec by using ^{60}Co source with coincident gates set to receive Comptons corresponding to 1275 and 123keV gamma rays involved in the present lifetime measurements. The source was prepared by depositing few drops of the radioactive solution on aluminized nylon film fixed at the centre of an aluminium ring of 5cm diameter and lmm width. This source was placed between the two detectors in a sandwiched geometry. Aluminium absorbers of lmm thickness were placed between the source and detector on each side in order to stop beta rays. Slope method was used to analyse the lifetime data.

MEASUREMENTS AND RESULTS

Angular Correlation Measurements

Gamma-gamma angular correlation measurements have been done on 9 cascades. The essential features of the decay scheme as required in the present work are shown in Fig. 1. The lifetime of the 123.04keV level (1.19nsec) causes an attenuation of angular correlations which involve this level as intermediate level. Therefore, the corresponding attenuation factors have been taken from the differential angular measurements of Lange *et al.* (1971) and are as

$$G_2 = 0.895 \pm 0.007 \; ; \; G_4 = 0.763 \pm 0.015$$

The angular correlation coefficients A_2 and A_4 for the cascades having one transition as 123.04keV have been corrected by these attenuation coefficients and are summarised in Table I. The analysis of multipole admixtures has been done using pure E2 nature of the 123.04keV transition. In the following sections, discussion of mixing ratio analysis is briefly given.

Multipole Admixture in 592keV Transition — The 592–(1005)–123keV cascade has been analysed to measure multipole mixing in the 591.80 keV transition. The

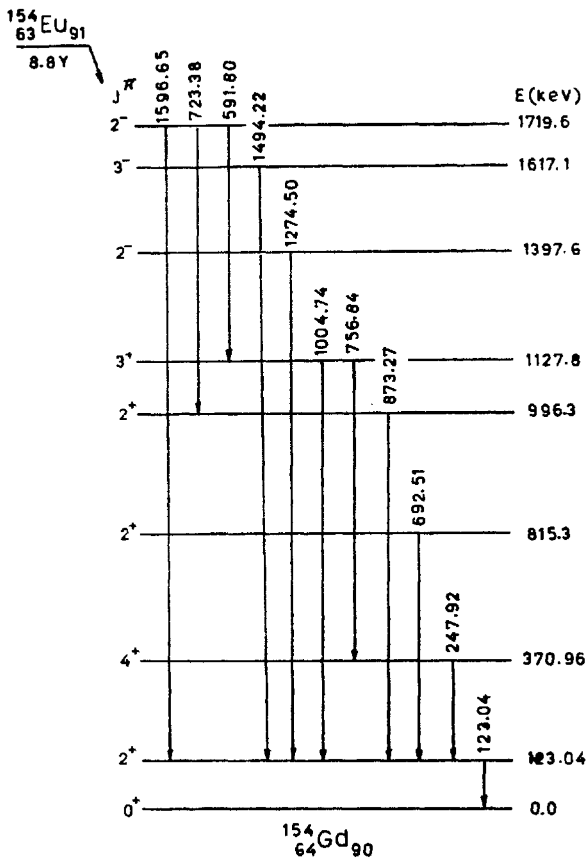

FIG. 1. Decay scheme of ^{154}Eu showing the levels of ^{154}Gd which are involved in the present angular correlation measurements.

TABLE I

Angular correlation results in ^{154}Gd

Cascade (keV)		Angular Correlation Coefficients			
		Present Work	Whitlock *et al.* (1971)	Gottel *et al.* (1972)	Gupta *et al.* (1977)
592–(1005)–	A_2	−0.025 (10)	—	−.067 (15)	−0 056 (7)
123	A_4	−0.031 (17)	—	−.019 (66)	0.044(15)
693–123	A_2	−0.143 (42)	−0.143 (22)	—	−0.166 (14)
	A_4	0.102 (71)	0.311 (40)	—	0.346 (26)
723–(873)–	A_2	−0.020 (14)	—	—	−0.045 (7)
123	A_4	0.039 (25)	—	—	0·033 (10)
757–(248)–	A_2	0.106 (21)	—	0.175 (36)	—
123	A_4	0.160 (38)	—	−0.181 (40)	—
873–123	A_2	−0.002 (9)	0.002 (12)	−0.006 (11)	0.004 (6)
	A_4	0.215 (19)	0.323 (1)	0.315 (12)	0.323 (1)
1005–123	A_2	−0.215 (19)	−0.239 (18)	−0.248 (16)	−0.302 (4)
	A_4	−0.075 (17)	−0.073 (26)	−0.088 (36)	−0.065 (10)
1275–123	A_2	0.202 (4)	0.234 (6)	0.218 (4)	—
	A_4	−0.020 (7)	—	0.026 (7)	—
1494–123	A_2	0.057 (74)	−0.075 (29)	—	−0.084 (31)
	A_4	−0.136 (127)	−0.022 (44)	—	−0.023 (24)
1597–123	A_2	0.184 (37)	0.196 (13)	0.259 (52)	0.254 (12)
	A_4	0.046 (63)	0.017 (21)	0.015 (40)	−0.037 (25)
757–248	A_2	0.129 (9)	0.161 (4)	0.185 (21)	0.150 (4)
	A_4	−0.118 (14)	−0.174 (6)	−0.158 (25)	−0.162 (5)

spin sequence for this cascade is already accepted to be $2^- - (3^+ - 2^+) - 0^+$ (Lederer & Shirley, 1978). The angular correlation coefficients A_2 and A_4 have been corrected for 1004.74keV unobserved transition by applying U_k coefficients as tabulated by Rose and Brink (1967). The mixing ratio analysis yields two values of $Q = 0.008 \pm 0.007$; $0.975^{+0.010}_{-0.015}$ for the 591.80keV transition. The second value of the quadrupole content (Q) is not supported by the conversion coefficient results of Brantley *et al.* (1968). Therefore, the first value of Q has been accepted which gives the multipole admixture in the 591.80keV transition to be E1 + $\leqslant$ 1.5 per cent M2.

Multipole Admixture in 693keV Transition — The multipole admixture in the 692.51keV transition has been culculated using the directional correlation coefficients for the 693–123keV cascade (Table I). This cascade follows the spin sequence $2^+ - 2^+ - 0^+$ (Lederer & Shirley, 1978). The graphical analysis for the 692.51keV transition yields two values of $Q = 0.245^{+0.060}_{-0.050}$; $0.985^{+0.010}_{-0.015}$. The experimental A_4 coefficient rejects the first value of Q. Therefore, the multipole admixture in the 692.51keV transition corresponds to the second value of Q and is found to be M1 + ($98.5^{+1.0}_{-1.5}$) per cent E2.

Multipole Admixture in 723keV Transition — The multipole mixing in 723.38 keV transition was calculated on the basis of 723–(873)–123 keV cascade results. This cascade follows a spin sequence 2^- —(2^+ — 2^+) — 0^+ (Lederer & Shirley, 1978). The mixing ratio analysis for this cascade yields two values of quadrupole content in the 723.38keV transition as $Q = 0.038^{+0.035}_{-0.025}$; $0.955^{+0.025}_{-0.040}$. The second value of Q has been rejected on the basis of conversion coefficient results of Brantley *et al.* (1968) and therefore, the multipole admixture in the 723.38 keV transition is found to be E1 + ($3.8^{+3.5}_{-4.0}$) per cent M2.

Multipole Admixture in 757keV Transition — The multipole mixing in 757 keV transition has been calculated from the analysis of 757–(248)–123 and 757–248keV cascades. The well defined spin sequences for the two cascades are 3^+–(4^+–2^+)–0^+ and 3^+–4^+–2^+ respectively (Lederer & Shirley, 1978). The mixing ratio analysis yields the following values of Q.

Cascade studied (keV)	Q_1	Q_2
757–(248)–123	$0.08^{+0.010}_{-0.015}$	0.980 ± 0.005
757–248	$0.10^{+0.010}_{-0.007}$	0.980 ± 0.005

The first value of Q has been rejected on the basis of conversion coefficient results (Brantley *et al.*, 1968). Therefore, the multipole admixture in the 756.84 keV transition is found to be Ml + (98.0 $\pm$ 0.5) per cent E2.

Multipole Admixture in 873keV Transition — The multipole mixing in the 873.27keV transition has been calculated from the analysis of 873–123keV cascade. This cascade follows the spin sequence 2^+–2^+–0^+. The graphical analysis for the 873.27keV transition yields two values of $Q = 0.10 \pm 0.01$; 0.995 ± 0.005. An analysis of the experimental A_4 coefficients favours the second value of Q which is also supported by the conversion coefficient results (Brantley *et al.*, 1968). Therefore, the second value of Q has been accepted according to which the multipole admixture in 873.27keV transition is found to be Ml + (99.5 $\pm$0.5) per cent E2.

Multipole Admixture in 1005keV Transition — The 1005–123keV cascade has been analysed in order to calculate multipole mixing in 1004.74keV transition. The accepted spin sequence for this cascade is 3^+—2^+—0^+ (Lederer & Shirley, 1978). The graphical analysis gives two values of Q = 0. 035 $\pm$ 0.005; 1.0 $\pm^{0.00}_{0.005}$. The experimental A_4 value alongwith the internal conversion results (Brantley *et al.*, 1968) exclude the first value of Q and therefore, the multipole admixture in the 1004.74 keV transition is almost E2 with $\leqslant$ 0.5 per cent Ml component.

Multipole Admixture in 1275keV Transition — The multipole mixing in 1274.50 keV transition is found on the basis of 1275–123keV cascade results. The spin sequence for this cascade is 2^-–2^+–0^+ (Lederer & Shirley, 1978). The mixing ratio analysis yields two values of $Q = 0.003 \pm 0.002$; 0.88 ± 0.005. The second value of Q is not supported by the conversion coefficient results (Brantley *et al.*, 1968).

Therefore, the 1274.50keV transition is found to be almost El with (0.3 ± 0.2) per cent M2 component.

Multipole Admixture in 1494keV Transition—The 1494–123keV cascade has been analysed to get the multipole mixing in 1494.22keV transition. This cascade follows a spin sequence $3^- - 2^+ - 0^+$ (Lederer & Shirley, 1978). The mixing ratio analysis yields two values of $Q = 0.033^{+0.060}_{-0.025}$; $0.885^{+0.060}_{-0.085}$. The second value of Q is not supported by the conversion coefficient results (Brantley *et al.*, 1968). Thus the multipole admixture in the 1494.22keV transition is found to be El + $(3.3^{+6.0}_{-2.5})$ per cent M2.

Multipole Admixture in 1597keV Transition—The multipole mixing in 1596.65 KeV transition has been calculated from the 1597–123keV cascade which follows the spin sequence $2^- - 2^+ - 0^+$ (Lederer & Shirley, 1978). The mixing ratio analysis yields two values of $Q = 0.005 \pm 0.005$; 0.89 ± 0.005. The second value of Q has been rejected on the basis of experimental value of A_4 and therefore, the multipole admixture in the 1596.65 keV transition is found to be El + $\leqslant$ 1.0 per cent M2.

Lifetime Measurements

For the measurement of lifetime of 123.04keV state in ^{154} Gd, the 1275-123keV delayed coincidence spectrum was recorded by selecting 1062KeV Compton energy corresponding to 1275keV gamma ray (windows set to observe upper 20 per cent of the Compton) in the start channel and the 40keV Compton energy corresponding to the 123KeV photopeak (window set to observe upper 75 per cent of the Compton) in the stop channel of the time-to-pulse height converter (TPHC). The selection of the two energies were done using two timing single channel analysers. The delayed time spectrum alongwith the prompt time spectrum (taken with ^{60}Co) as recorded in the present study is shown in Fig. 2.

The linear part of the delayed curve obtained after subtracting chance coincidences observed in the time spectrum was analysed by taking several groups of channels (each group containing 40 channels) and by using the Slope Method for the analysis. The lifetime of the 123.04 keV state in ^{154}Gdis found to be $T_{1/2}$ = 1.19 ± 0.03nsec. This value is in fair agreement with the earlier results (Lederer & Shirley, 1978).

Conclusion

The multipole admixtures in various transitions measured in the present work are, in in general, agreement with the results of previous workers (Table II). In the case of 1494.22 keV transition, the M2 admixture is found more than that reported by Whitlock *et al.* (1971) and Gupta *et al.* (1977) (Table II). Similarly in case of 723.38keV transition, the present value of M2 component is higher than that reported by Gupta *et al.* (1977). The present results show that Ml component in the $2^+_\beta - 2^+_g$ and

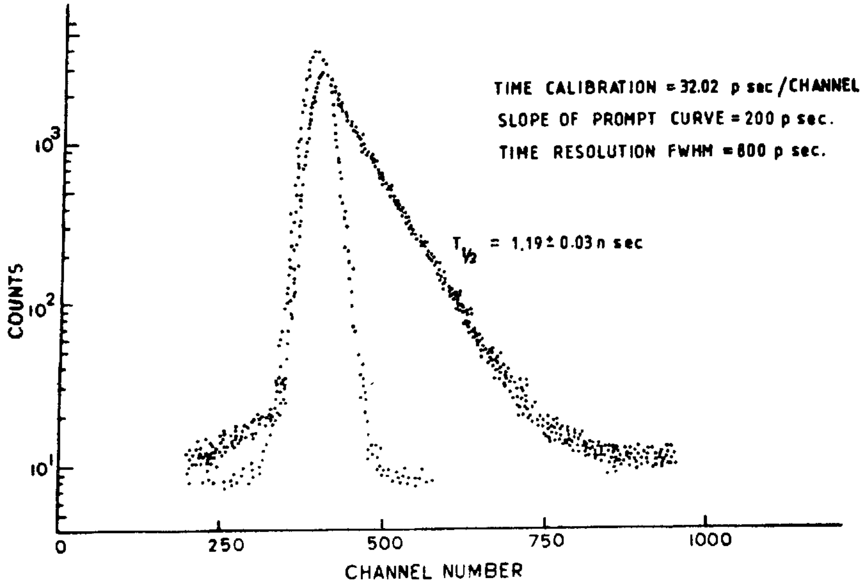

FIG. 2. The 1275–1239keV delayed coincidence curve for the lifetime measurement of the 123.04keV level in ^{154}Gd together with the normalised prompt curve.

TABLE II

Multipole admixtures for various transitions in ^{154}Gd

Cascade (keV)	Transition Energy (keV)	Multipole Admixture		
		Present work	Whitlock *et al.* (1971)	Gupta *et al.* (1977)
592–(1005)–123	592	E1 + $\leqslant$ 1.5 % M2	—	$(99.6^{+0.3}_{-0.4})$ % E1
693–123	693	M1 + $(98.5^{+1.0}_{-1.5})$ % E2	M1 + $(99.18^{+0.31}_{-0.72})$ % E2	(98.3 ± 0.5) % E2
723–(873)–123	723	E1 + $(3.8^{+3.5}_{-4.0})$ % E2	—	$(99.75^{+0.24}_{-0.55})$ % E1
757–(248)–123	757	M4 + (98.0 ± 0.5) % E2	—	—
873–123	873	M1 + (99.5 ± 0.5) % E2	M1 + $(99.0^{+0.22}_{-0.25})$ % E2	(98.9 ± 0.2) % E2
1005–123	1005	E2 + $\leqslant$ 0.5 % M1	M1 + $(99.78^{+0.20}_{-0.23})$ % E2	(98.4 ± 0.1) % E2
1275–123	1275	E1 + (0.3 ± 0.2) % M2	—	—
1494–123	1494	E1 + $(3.3^{+6.0}_{-2.5})$ % M2	100 % E1	$(99.96^{+0.04}_{-0.05})$ % E1
1597–123	1597	E1 + < 1.0 % M2	>99.5 % E1	>99.95 % E1
757–248	757	M1 + (98.0 ± 0.5) % E2	M1 + (97.0 ± 0.3) % E2	(97.4 ± 0.2) % E2

$2^+_\gamma - 2^+_g$ transitions (692.51 and 873.27keV) is very small i.e., $(1.5^{+1.5}_{-1.0})$ per cent per cent and (0.5 ± 0.5) per cent respectively. Therefore, it is concluded that these transitions do not contain large Ml admixtures, which is in agreement with the experimental results of Whitlock *et al.* (1971) and Gupta *et al.* (1977). This is not in favour of the predictions of Mottelson (1968) on the basis of theoretical model.

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