DIRECTIONAL CORRELATIONS OF GAMMA RAYS IN THE DECAY OF W^{187}

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Gamma-gamma directional correlations are measured for the cascades 72–134 keV and 552–134 keV in Re^{187} following the beta decay of 24 hW^{187}. The results favour a spin of 9/2 for the 206 keV level and 5/2 for the 686 keV level and support the recent findings from the (d, d′) and (α, α′) inelastic scattering experiments in Re^{187}. From the measured E2/M1 mixing ratio of the 134 keV transition, transition probabilities of the M1 and the E2 components are estimated and compared with the Weisskopf and the Nilsson estimates.

Introduction

Level structure of Re^{187} has been studied in the past by several authors (Dubey *et al.* 1957; Behrend and Neuert 1958; Klimentovskaya and Shavrin 1959; Arns and Wiedenbeck 1960; Vergnes 1960; Gallagher *et al.* 1960; Michaelis 1963*a*, *b*; Han *et al.* 1963; Bisgård *et al.* 1962, 1965; Bashandy *et al.* 1965; Funke *et al.* 1965). Though there is general agreement over the orbitals of most of the excited levels, discrepancies still seem to exist about the spin assignment of the 206 and 686 keV levels. ICC measurements of Vergnes (1960), Gallagher *et al.* (1960), Edwards and Boehm (1960) and Han *et al.* (1963) lead to spin 9/2 for the 206 keV level. Behrend and Neuert (1958), however, assigned spin 3/2 to this level on the basis of their angular correlation studies. On the other hand, the results of Klimentovskaya and Shavrin (1959) and Michaelis (1963) using the same technique gave a spin of 9/2 for this level. Similarly for the 686 keV level conflicting spin assignments of 5/2 and 7/2 have been made from the internal conversion and directional correlation methods, respectively (Vergnes 1960; Gallagher *et al.* 1960; Han *et al.* 1963; Arns and Wiedenbeck 1960; Michaelis 1963*a*, *b*; Klimentovskaya and Shavrin 1959).

In view of the above uncertainties, it was felt that detailed coincidence and angular correlation measurements would be of value in establishing the spin value of the 206 and the 686 keV levels. Further, from the results, the mixing ratio E2/M1 for the 134 keV transition has been analysed and an estimate has been made for the transition probabilities for the M1 and E2 components of the 134 keV transition.

Experimental Procedure

All coincidence measurements were carried out using a fast-slow coincidence scintillation spectrometer used by us earlier (Gupta and Saha 1965*a*, *b*). This has an effective resolving time of ≈ 30 ns. In coincidence measurements, both the detectors were covered frontally with ~ 6 mm thick perspex discs to reduce the beta contribution. A Compton shield was also used between the two detectors in order to eliminate the counter-to-counter scattering. In the directional correlation measurements, the data were corrected for source decay, random coincidences and the electronic drifts.

Gamma-ray scintillation spectrum of W^{187} showed no evidence of any impurity activity being present in the source. Measurements were carried out early in the decay of the source in order to eliminate interference from the negligible amount of long-lived W^{181}. The relevant coincidence spectra

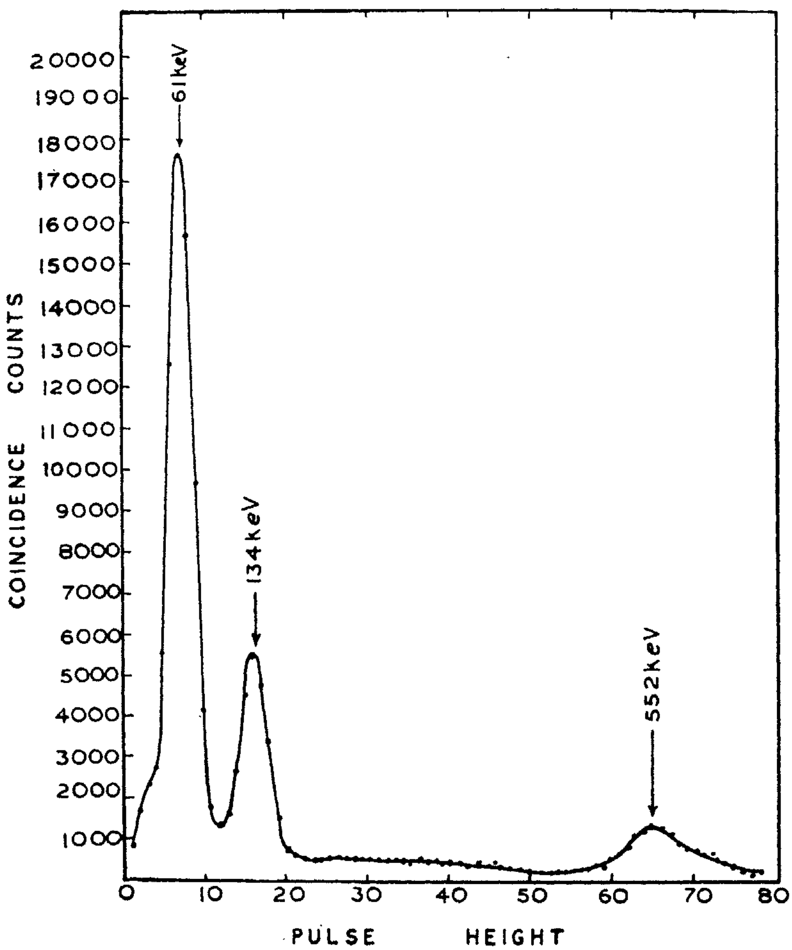

FIG. 1. Gamma-ray spectrum in coincidence with the 72 keV region.

reproduced in Figs. 1–3 were taken by gating on the 72, the 134 and the 552 keV energy regions. The spectra were critically examined and used in the evaluation of the directional correlation data, where found necessary.

Results

(a) *Directional Correlation of the 72–134 keV Cascade*

The solid angle corrected angular correlation function was found to be

$$W(\theta) = 1-(0{\cdot}0113\pm0{\cdot}0075)P_2\,(\cos\theta)-(0{\cdot}0217\pm0{\cdot}0217)P_4\,(\cos\theta). \quad .. \quad (1)$$

The main interference in the above result is due to the coincidence of γ 134

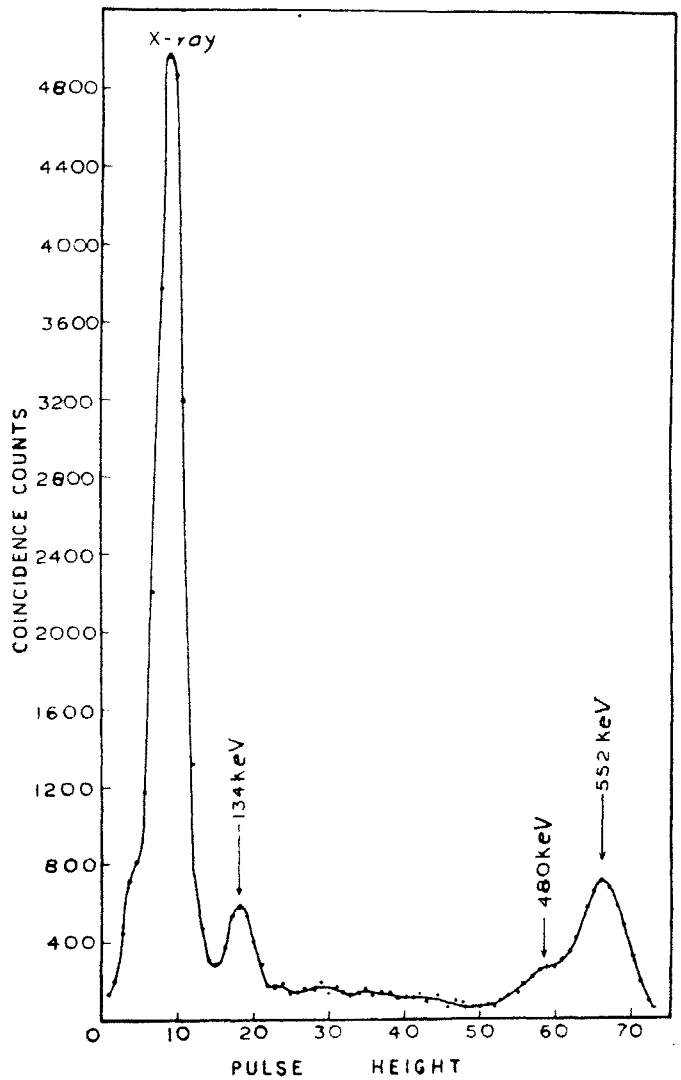

Fig. 2. Gamma-ray spectrum in coincidence with the 134 keV region.

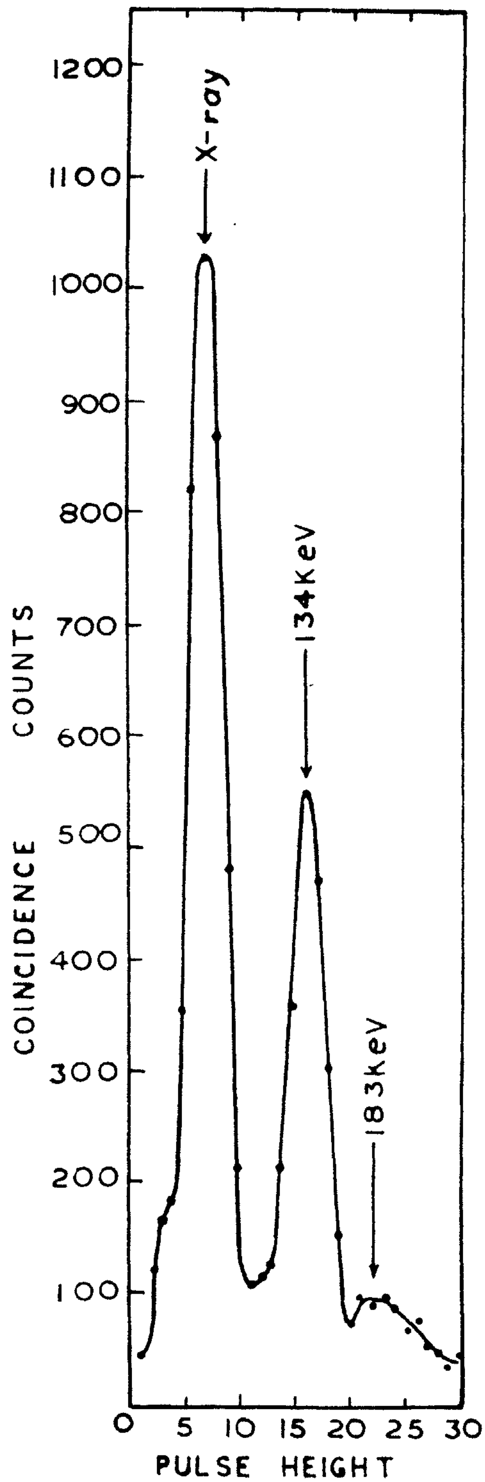

FIG. 3. Gamma-ray spectrum in coincidence with the 552 keV region.

with the K X-ray ($\sim$ 61 keV) from the K conversion of the 72 keV radiation. Other contributions appear to arise from the coincidence of (a) γ 134 with the 61 keV conversion quanta of γ 552, (b) the 61 keV conversion quanta of γ 134 with the 134 keV Compton electrons of γ 552 and (c) γ 134 with the 72 keV Compton electrons of the 552 keV radiation. These contributions were found to be negligible and are, therefore, not considered here. Considering the iodine K X-ray escape probability and the fluorescence yield, the main contribution due to the coincidence of γ 134 with the 61 keV K X-ray of the 72 keV radiation, as mentioned above, comes out to be ($48{\cdot}5 \pm 5{\cdot}8$) per cent of the observed coincidences. As this interference is isotropic in nature, the directional correlation function, after correction, turns out to be

$$W(\theta) = 1-(0{\cdot}0219\pm0{\cdot}0146)P_2(\cos\theta)-(0{\cdot}0421\pm0{\cdot}0426)P_4(\cos\theta). \quad (2)$$

Our A_2 value agrees fairly well with that obtained by Michaelis (1963a) within the statistical error, but differs appreciably from that obtained by Behrend and Neuert (1958).

As the half life of the intermediate level at 134 keV is $\sim 1{\cdot}04\times10^{-11}$ sec (Mössbauer and Wiedemann 1960), attenuation of the correlation function seems hardly possible. The eqn. (2), therefore, represents the true correlation function and is analysed below.

The spin of the ground state of Re^{187} has been shown to be 5/2 by Segel and Barnes (1957) and that of the first excited state at 134 keV to be 7/2 from the Coulomb excitation (Bernstein and Lewis 1957; de Boer *et al.* 1959) and the internal conversion data (Gallagher *et al.* 1960). Considering these spin values, eqn. (2) is found to be consistent with spin 9/2 only for the 206 keV level. Starting from the assumption that the 72 keV radiation is pure E1, the mixing ratio analysis of eqn. (2) in terms of a $9/2(D,\ Q)7/2(D,\ Q)5/2$ spin sequence (Fig. 4) leads to the M1 multipolarity of the 134 keV radiation with a quadrupole content (E2 admixture) of $Q_{134} = 0{\cdot}065\pm0{\cdot}025$ or $Q_{134} = 0{\cdot}994 \pm0{\cdot}004$. For one thing, this assumption is supported by the internal conversion results of Han *et al.* (1963) and Bisgård *et al.* (1962, 1965a). However, from the ICC measurements of Gallagher *et al.* (1960) and the angular correlation studies of Koički *et al.* (1963) on the 480–72 keV cascade, the value 0·01 can be taken as an upper limit of the M2 admixture in the predominantly E1 72 keV radiation. With $Q_{72} \leqslant 0{\cdot}01$, eqn. (1) gives $Q_{134} = 0{\cdot}138\pm0{\cdot}083$ or $Q_{134} = 0{\cdot}958\pm0{\cdot}038$. The higher values of Q_{134} are ruled out on the basis of the ICC data (Gallagher *et al.* 1960) which favour predominantly M1 character for the 134 keV transition with an E2 admixture $\leqslant 0{\cdot}25$. The present results, therefore, have narrowed down the above limit to 6·5 per cent to $\sim$ 14 per cent which is more consistent with a recent finding ($Q_{134} \approx 3$ per cent) of Novakov and Hollander (1964) from the L-subshell measurements.

(b) Directional Correlation of the 552–134 keV Cascade

In this case the cascade is practically free from interfering effects.

The directional correlation function after applying the angular resolution correction was found to be

$$W(\theta) = 1-(0{\cdot}0235\pm0{\cdot}0132)P_2\,(\cos\theta)+(0{\cdot}0299\pm0{\cdot}0235)P_4\,(\cos\theta). \quad (3)$$

This result is fairly in good agreement with that obtained by Michaelis

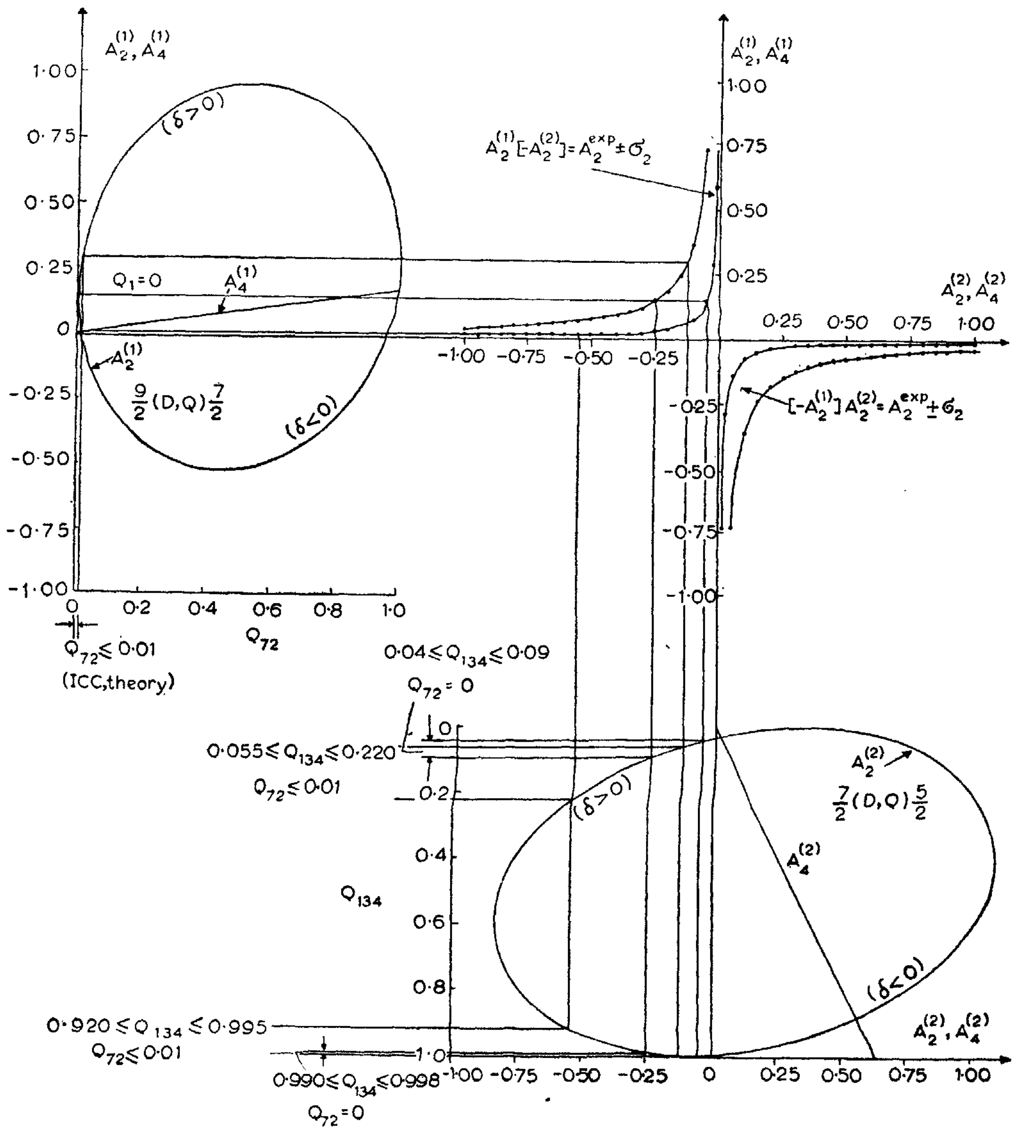

Fig. 4. Mixing ratio analysis of the 72–134 keV cascade in terms of a 9/2(*D*, *Q*)7/2(*D*, *Q*)5/2 spin sequence.

(1963*a*) but considerably deviates from that reported by Arns and Wiedenbeck (1960).

On the basis of the available experimental data on the level scheme of Re^{187}, three spin values for the 686 keV level are possible, namely 5/2, 7/2 or 9/2. Presuming a maximum of $\sim$ 25 per cent E2 admixture in γ 134 and a maximum of $\sim$ 2 per cent M2 admixture in γ 552, both on the basis of the ICC data (Gallagher *et al.* 1960), the theoretical limits of A_2, corresponding to the three possible spin sequences, are

(i) $5/2(D, Q)7/2(D, Q)5/2 \rightarrow -0{\cdot}030 \geqslant A_2 \geqslant -0{\cdot}368$

(ii) $7/2(D, Q)7/2(D, Q)5/2 \rightarrow +0{\cdot}315 \geqslant A_2 \geqslant +0{\cdot}188$

(iii) $9/2(D, Q)7/2(D, Q)5/2 \rightarrow +0{\cdot}3675 \geqslant A_2 \geqslant -0{\cdot}210$,

where (D, Q) denote the dipole and quadrupole contents in a transition. The experimental $A_2 = -(0{\cdot}0235 \pm 0{\cdot}0132)$ value, obtained by us, appears to favour the spin sequences (i) and (iii) only. The spin 9/2 for the 206 keV level is fairly certain from the present measurement of gamma-gamma directional correlation of the 72–134 keV cascade. In view of the well-established E2 multipolarity of the 480 keV transition (Han *et al.* 1963; Bisgård *et al.* 1962, 1965*a*) between the 686 and the 206 keV levels, a spin of 9/2 for the 686 keV level seems unlikely. The only possible alternative for this is a spin 5/2, confirming the spin sequence (i). Another support for this spin assignment is probably the value of A_4 coefficient $[+(0{\cdot}0299 \pm 0{\cdot}0235)]$, which may be taken as non-zero positive value, in spite of the large statistical error. This is consistent with our mixing ratio analysis, carried out for the 552 keV radiation.

The graphical analysis of eqn. (3) in terms of a $5/2(D, Q)7/2(D, Q)5/2$ spin sequence is shown in Fig. 5. Using the result $Q_{134} = 0{\cdot}138 \pm 0{\cdot}083$ from the preceding subsection, eqn. (3) gives $Q_{552} \leqslant 0{\cdot}02$. The 552 keV radiation, therefore, consists of $\sim$ 2 per cent M2 and $\sim$ 98 per cent E1 radiation. This is in excellent agreement with the value $Q_{552} \leqslant 0{\cdot}01$, obtained by Gallagher *et al.* and $Q_{552} \leqslant 0{\cdot}03$, reported by Michaelis.

Discussion

Re^{187}, which has 75 protons and 112 neutrons, lies in the transition region between the rotational nuclei having high deformation parameter and those having small equilibrium deformation. The ground state of this nucleus, whose spin value has been measured to be 5/2, is considered as the Nilsson state 31, as this is the only state of spin 5/2 which can be expected in this region. The parity of this state then turns out to be positive (Gallagher *et al.* 1960). According to Nilsson diagram, the orbitals of the first intrinsic excitation of Re^{187} must be 9/2. This corresponds to the 206 keV metastable state in Re^{187} and not to the 134 keV first excited state with a spin of 7/2. The 134 keV level, on the other hand, is considered as the first rotational excitation arising due to the configuration of the ground state. The present work on the 72–134 keV cascade supports the spin value of 9/2 for the metastable state at 206 keV, as is also required by the Nilsson description. Similarly, for the 686 keV level, Gallagher *et al.* show that it is most likely a gamma vibrational state built on the 206 keV metastable state. This is known to have a spin value of 5/2. Our spin assignment for this level agrees with this value. Spin value of 7/2, as obtained by others for this level (Arns and Wiedenbeck 1960), would be difficult to explain. These conclusions are

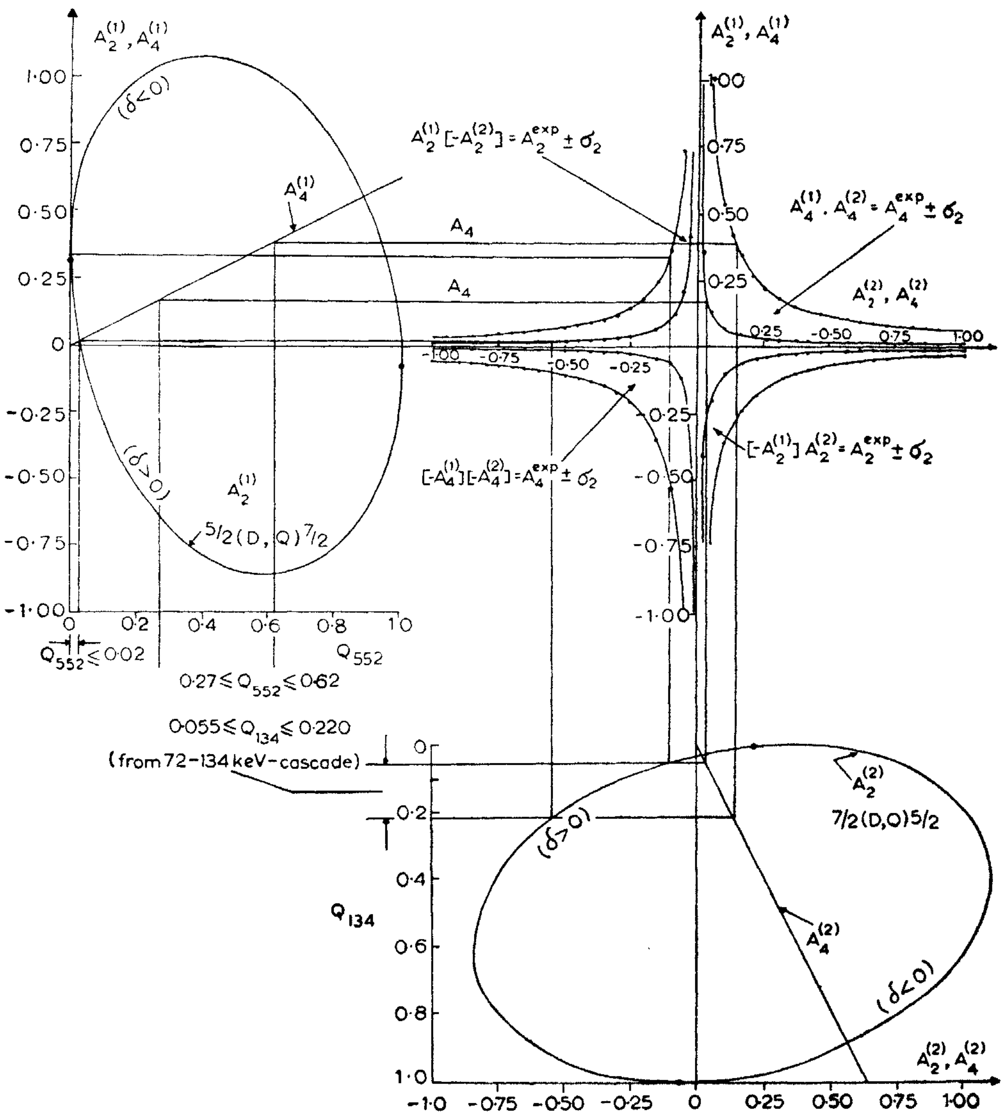

FIG. 5. Mixing ratio analysis of the 552–134 keV cascade in terms of a 5/2(*D*, *Q*)7/2(*D*, *Q*)5/2 spin sequence.

TABLE I

Transition probabilities (T) *for the* M1 *and* E2 *components of the* 134 keV *radiation* ($7/2^+ \rightarrow 5/2^+$) ($\alpha_T(134) = 2 \cdot 2$. $T_{1/2}(134) = 10^{-11}$ sec.)

Component	T^*_{exp} (other workers)	T_{exp} (present work)	$T_{Weisskopf}$	$T_{Nilsson}$	$T_{exp}/T_{Weisskopf}$		$T_{exp}/T_{Nilsson}$	
					Other authors*	Present work	Other authors*	Present work
M1	$2 \cdot 4 \times 10^{10}$	$2 \cdot 0 \times 10^{10}$	$7 \cdot 47 \times 10^{10}$	$2 \cdot 8 \times 10^{10}$	0·32	0·27	0·9	0·7
E2	$7 \cdot 1 \times 10^{8}$	14×10^{8}	$3 \cdot 41 \times 10^{6}$	$7 \cdot 0 \times 10^{8}$	200	414	1	~2

* Computed from the measurements of McGowan and Stelson (1958), Blaugrund *et al.* (1963) and Mössbauer and Wiedemann (1960).

fully in accord with the recent findings of Bisgård *et al.* (1965*b*) from the experiments on inelastic scattering (d, d') and (α, α') in Re^{187}.

Using the measured quadrupole admixture, Q_{134}, for $Q_{72} = 0$ and the known values of α_T^{134} and the half-life of the 134 keV state, the transition probabilities for the M1 and the E2 components of the 134 keV radiation are computed. The results are shown in Table I. Corresponding values using the earlier measurements of other workers are shown in column 2. Comparison of experimental transition probabilities with the Weisskopf and the Nilsson estimates shows that the Nilsson's deformed nucleus picture accounts fairly well for ${}_{75}Re^{187}_{112}$.

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