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## CONTENT

# ABSTRACT

An activity of $^{158}$Eu was produced by an (n,p) reaction upon an enriched gadulinum target by means of 14 MeV neutrons obtained from a SAMES generator. The gamma radiation accompanying the beta decay of $^{158}$Eu into $^{158}$Gd was detected by means of a Ge (Li) spectrometer. A 24-level decay scheme was devised and the transition probabilitiee were analyzed in terms of adiabatic theory and also including band mixing effects. The values of beta radiation intensities obtained from the experiment were compared with theoretical predictions calculated on the basis of the Nilsson model.

Keywords: radioactivity, gamma-spectroscopy.

# ZUSAMMENFASSUNG

Ein angereichertes Gadolinium Target wurde mit 14 MeV Neutronen eines SAMES Neutronengenerators bestrahlt und durch eine (n,p)-Reaktion Europium 158 erzeugt. Die beim Beta-Zerfall von $^{158}$Eu zu $^{158}$Gd entstehende $\gamma$-Strahlung wurde mit einem Ge(Li)-Detektor gemessen. Ein aus 24 Niveaus bestehendes Zerfallsschema wurde aufgebaut. Die Übergangswahrscheinlichkeiten unter Einfluß der adiabatischen Theorie und von Band-Mischungseffekten wurden untersucht. Die experimentellen Werte wurden mit theoretischen nach dem Nilsson Modell berechneten Werten verglichen.

Stichworte: Radioaktivität, Gamma Spektroscopie

## 1. Introduction

The product of $^{158}Eu$ to $^{158}Gd$ decay belongs to doubly even deformed nuclei. This group of nuclei has the following possible modes of excitation: $\beta$ - and $\gamma$ - quadrupole vibrations, octupole vibrations, two-particle excitations and rotational bands built on them. The ground state rotational $\beta$ - and $\gamma$- vibrational levels couple with one another, which complicates theoretical description. It was felt that an investigation of energy levels and transition probabilities of these nuclei would provide valuable information about the correlation of nucleonic motions.

The decay of $^{158}Eu$ had been previosuly investigated by Daniels and Hoffman (Ref. 1) as well as Schima and Katoh (Ref.2), who established its basic features. The excited levels of $^{158}Gd$, fed by the decay of $^{158}Tb$, had been studied by Paperiello et al. (Ref. 3) and Groshev et al. (Ref. 4), who measured the conversion electrons' spectrum resulting from the (n, $\gamma$) reaction upon $^{157}Gd$. Collective vibrational states in even Gd isotopes had been investigated on the basis of the inelastic scattering of deuterones by Bloch et al. (Ref. 5). Bollinger and Thomas (Ref. 6) showed the possibilities of determining parities and spins of nuclei by means of the average resonance method of neutron capture gamma ray spectroscopy using a $^{158}Gd$ gadolinum isotope as an example. Beta und gamma vibrational levels had been previously discussed by Kluk et al. (Ref. 7). The low-lying collective states of $^{158}Gd$ had been studied by Baader (Ref. 8) by means of the (n, $\gamma$) reaction; his results, however, were inconclusive, especially as regards states above 1.5 MeV.

This paper presents experimental data concerning the $^{158}Gd$ structure as a function of $^{158}Eu$ decay.

## 2. Experimental Procedure

The sources were prepared by means of an (n,p) reaction upon a 300 mg $Gd_2O_3$ target with mass 158, enriched to 92 %. The 14 MeV neutrons were produced by a SAMES generator. The samples were wrapped in gold foils and packed between cadmium sheets in order to reduce thermal neutrons. The gold and cadmium foils were removed prior to commencing the measurements. The irradiation time was varied from 60 to 90 minutes.

$^{159}$Gd and $^{155}$Sm, produced by $(n,\gamma)$ and $(n,\alpha)$ reactions respectively were the main impurities, but their admixtures were not meaningful except for the low energy region of the gamma spectrum where they were easily distinguishable on the basis of their half-lives.

The $^{158}$Eu spectra were measured by means of a 30 cm$^3$ Ge(Li) detector connected to a Tennelec TC 203 amplifier. Pulses generated by an ADC (Geoscience, model 8050) were fed to a PDP-8 computer, which was used as a multichannel analyser and performed a preliminary data analysis.

The detector was shielded from the source by a 1 cm plexiglas and a 4 mm of aluminum sheet. A 5-cm thick lead shielding was used to reduce room background radiation. Different source distances were used in order to account for the summing of the pulses in the crystal. The decay of $^{158}$Eu was observed for 5÷7 half lives. The efficiency response of the germanium detector was found by means of $^{57}$Co, $^{133}$Ba, $^{226}$Ra, $^{152}$Eu sources. Sources $^{137}$Cs, $^{60}$Co, $^{133}$Ba, $^{226}$Ra were used for the energy calibration of the crystal. The energy and efficiency curves were constructed by fitting the appropriate polynomial to the experimental points with the aid of a computer program.

## 3. Results

The gamma spectrum of $^{158}$Eu decay is presented in Figure 1. The results were evaluated by means of a procedure based on Fourier transforms described in Ref. 9, and by a least-squares fit. In the transformed domain, the experimental gamma spectrum was smoothed by means of filtering. Portions of the spectrum before and after smoothing are presented in Figure 2. In the case of closely spaced doublets, a method of dividing the power spectrum minima by the instrument distortion function in the Fourier-transformed domain was used (Ref. 9). This method permits the resolution of the distance and amplitude ratio of two peaks differing by as little as 2÷3 channels, even if the peak width is 10 or more channels. Figure 3 illustrates the application of this method in the case of multiple doublets in the $^{158}$Eu gamma spectrum. The energies and the intensities of gamma rays emitted by $^{158}$ Eu are presented in Table I.

The decay scheme, shown in Figure 4, was arrived at with the aid of a computer program. The results published in references 7 and 8 were particulary helpful in establishing low-lying levels.

The log ft values are presented in Table II. They are based on the gamma ray intensities given in Table I.

In line with Ref. 2, which attributes 5 % feeding to the ground and first excited states, we assumed 5 % feeding for the ground state. The electron conversion coefficients were taken from tables by Hager and Seltzer (Ref. 10).

## 4. Discussion

### 4.1. Level Spins, Parities and γ-Transition Probabilities

The ground state rotational band of $^{158}$Gd had already been identified by Schima and Katoh (Ref. 2). The K[x/] = $1^-$ octupole band with spins $1^-$ (977.2 keV), $2^-$ (1023.8 keV) and $3^-$ (1041.3 keV), the K = $2^+$ gamma vibrational band (1187.1 keV and 1265.5 keV) and the K = $0^+$ pair-vibrational band (1195.6 keV and 1260.4 keV) had been discussed previously by Kluk et al. (Ref. 8) and Baader (Ref. 8). The high-spin members of those bands, not populated in the decay of $^{158}$Eu, had also been identified in the latter reference. The collective character of the 1517.4 keV level had been indicated by the (d,d') reaction cross-section measured by Bloch et al. (Ref. 5). In gamma transitions from this level to the ground state band, the considerable E0 admixture (Ref. 4) is characteristic of beta-vibration band members.

Table III presents the octupole states of $^{158}$Gd, along with the ratios of reduced transition probabilities B(L) from these states.

Under the adiabatic assumption that the collective motion is separable from the intrinsic motion of nucleons, Alaga et al. (Ref. 11) predicted the ratios of reduced transition probabilities (i.e. branching ratios) from a level of one rotational band to the levels of another band, according to the following formula:

$$\frac{\mathrm{Int}_1 \cdot E_2^{2L+1}}{\mathrm{Int}_2 \cdot E_1^{2L+1}} = \frac{B(L)_1}{B(L)_2} = \left| \frac{\langle I_i\ L\ K_i\ \ (K_f - K_i) \mid I_{f1}\ K_f \rangle}{\langle I_i\ L\ K_i\ \ (K_f - K_i) \mid I_{f2}\ K_f \rangle} \right|^2$$

where: $\mathrm{Int}_{1,2}$, $E_{1,2}$ are the intensities and energies of the first and second transition respectively;

$\langle \mid \rangle$ is the Clebsh-Gordan coefficient;

B(L) represents reduced transition probabilities of multipolarity L;

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[x/] K represents the projection of spin of the nucleus on its symmetry axis.

$K_i$, $K_f$ are the projections of the spins $I_i$, $I_f$ on the symmetry axis of nucleus for the initial and final states respectively.

In the case of $^{158}$Gd, the adiabatic assumption does not hold. As can be seen in Table III, the agreement with the Alaga rule is rather poor. The factor K ceases to be a good quantum number because of the coupling of collective and intrinsic motion in deformed nuclei. In order to account for this effect, Michailov (Ref. 12) considered the wave function of the rotational state as a super-position of states having different K factors. Michailov gave the following expression for the ratio of reduced transition probabilities:

$$\frac{B(L)_1}{B(L)_2} = \left[\frac{\langle I_i\ L\ K_i\ (K_f-K_i)\ |\ I_{f1}K_f\rangle}{\langle I_i\ L\ K_i\ (K_f-K_i)\ |\ I_{f2}K_f\rangle}\right]^2 \frac{\left\{1+\left[I_{f1}(I_{f1}+1)-I_{i1}(I_{i1}+1)\right]a\right\}^2}{\left\{1+\left[I_{f2}(I_{f2}+1)-I_{i2}(I_{i2}+1)\right]a\right\}^2}$$

where a is a parameter, and the other symbols are the same as in expression (1).

Parameter a, defined as the spin-independent amplitude of admixed transition may be determined experimentally. In the case of more than two transitions from the same level, one can check the value of parameter a on the basis of the self-consistence of results obtained from the two branching ratios. For a = 1, expression (2) changes into expression (1). As can be seen from Table III, Michailov's rule yields a better agreement with experimental results than Alaga's expression. More accurate results may be obtained by using a more detailed mode. Neergard and Vogel (Ref. 13) and Kocbach and Vogel (Ref. 14) calculated the branching ratios for E3 and E1 transitions deexciting the octupole states in even-even deformed nuclei using the quasi-particle random phase approximation with pairing and the octupole-octupole force as a residual interaction. The Coriolis coupling between octupole states with different K factors was also taken into account. Calculated in this way, the theoretical branching ratios are quite close to the experimental values (refer to Table III). The advantage of Michailov's formula (Ref. 12) is, that it accounts for the effect of band mixing without having to specify the interacting bands; thus it is not necessary to know the character of the states in question. This formula is therefore very useful in the analysis of higher-lying states of $^{158}$Gd. For the levels of $^{158}$Gd above 1.5 MeV there is less information available. Nevertheless, certain conclusions concerning the quantum characteristics of these states can be drawn from the log ft values and gamma-transition rates, by means of Michailov's formula.

The 1793.1 keV level corresponds to the 1800 keV level measured by Schima and Katoh (Ref. 2) by means of scintillation techniques, and to the 1795 keV level found by Groshev et al. (Ref. 4). Baader (Ref. 8) had assigned spin $2^-$ to the 1793.1 keV level. This value is in contradiction with the positive parity attributed to this level by Bollinger and Thomas (Ref. 6). Our results also indicate the positive parity of this state. The log ft being equal to 7.7 indicates allowed or first forbidden beta transition ($\Delta I = 0,1$), and eventually a unique transition ($\Delta I = 2$, change of parity) from the $1^-$ ground state of $^{158}$Eu to the discussed level; thus the possible spin assignments for this level are $0^{\pm}$, $1^{\pm}$, $3^+$. Spin values $0^{\pm}$, $1^{\pm}$ and $2^-$ have been eliminated by the 1529.4 keV transition to the $4^+$ level. Spin $3^+$ has been eliminated by the decay to $1^-$ state. This leaves only spin $2^+$ for the 1793.1 keV state.

Table IV compares the experimental and theoretical branching ratios for some higher-lying levels of $^{158}$Gd. For the discussed level, $K = 2$ yields the best agreement with that predicted by Michailov's rule. Thus this value of K is suggested for the 1793.1 keV level.

The following transitions prove the existence of the 1848.1 keV level: 824.3 keV and 871.0 keV to the $1^-$ octupole band, and 1766.7 keV to the $2^+$ level of the ground state band. The value of log ft for this level is equal to 7.6 which makes possible spin assignments $0^{\pm}$, $1^{\pm}$, $2^{\pm}$, $3^+$. The last value is eliminated by the transition to the $^-$ state. Values $0^+$ and $0^-$ are not probable because of the existence of the $\gamma$-transitions to $2^-$ and $2^+$ levels respectively.

The experimental branching ratio for transitions to the members of $1^-$ octupole band is $\frac{B\ /\ I_i \rightarrow 1^-\ /}{B\ /\ I_i \rightarrow 2^-\ /} = 0.85 \pm 0.15$.

This value is close to that predicted by the Alaga rule for $I_i = 1$. Branching ratios for some E 1 transitions according to Alaga (Ref. 11) are as follows:

| $\frac{I_i \rightarrow I_{f1}}{I_i \rightarrow I_{f2}}$ | K = 0 | K = 1 | K = 2 |
|---|---|---|---|
| $\frac{1^+ \rightarrow 1^-}{1^+ \rightarrow 2^-}$ | 1 | 1 | - |
| $\frac{2^+ \rightarrow 1^-}{2^+ \rightarrow 2^-}$ | 0.2 | 1.8 | 0.467 |

As can be seen, $1^-$ is the most probable value of spin for the 1848.1 keV level. The 1894.5 keV level, corresponding to the 1898 keV level reported by Groshev et al. (Ref. 4) was also observed by Bollinger and Thomas (Ref. 6), who reported the parity of this state as being positive. Although a log ft value of 8.2 makes spin choices $0^\pm$, $1^\pm$, and $3^\pm$ possible for this level, the gamma transition to the $1^-$ level eliminates spin $3^+$, and the transition to the $3^-$ level eliminates spins $0^+$ and $1^+$. The choice of $2^+$ for the 1894.5 keV level follows from these considerations. The experimental value of 1.56 ± 0.29 for the branching ratio to the members of the $1^-$ octupole band agrees well with the theoretical value of 1.78 predicted by the Alaga rule for K = 1. The same arguments hold for the 1930.0 keV level as for the 1948.1 keV state, since the log ft value is also about 7, and the gamma-decay of this state to the $1^-$,$2^-$, and $2^+$ levels eliminates $0^\pm$ and $3^\pm$ as possible spin choices. *Bollinger and Thomas (Ref. 6) had established positive parity* for this level. On the basis of the Alaga rule, the branching ratio of 0.84 ± 0.17 to the $1^-$ and $2^-$ members of the vibrational band suggests the assignment of $1^+$ to the 1930.0 keV level, but the value $2^+$ cannot be excluded.

The existence of 1963.8 keV level is established by seven transitions, which fit very well into the energy sum relationships. A log ft value equal to 7.1 and the occurrence of $\gamma$-transitions to the levels of spins $0^+$, $1^-$, $2^\pm$, and $3^-$ leaves only the spin value of $2^+$ for the 1963.8 keV level. The experimental branching ratios to the ground state band and the $1^-$ octupole band are in agreement with the value obtained by means of Michailov's rule for K = 2 (refer to Table IV). For K = 0 and K = 1, it is not possible to find a valid parametor a for all transitions to the members of the same band.

Among the other higher-lying states, the following levels were reported previously: 2023.8 keV by Daniels and Hoffman (Ref. 1) and Bollinger and Thomas (Ref. 6); 2324.8 keV (Ref. 1 and Ref.6) as a positive parity state; 2394.9 keV as a tentative energy level 2440 keV (Ref. 2); and 2396 keV (Ref. 4).

The suggested spins and parities shown in the decay scheme (Fig.4) for levels from 2023.7 keV to 2498.6 keV are based on considerations concerning log ft values and branching ratios similar as to those used for the levels discussed previously.

Only for the 2324.8 keV level, whose gamma-transitions to all three members of $1^-$ vibrational band were found, was it possible to compare the branching ratios with Michailov's rule (Table IV). The agreement found for spin projection K = 1 was quite good. The quantum numbers suggested for this state are I = 2, K = 1, with positive parity. In conclusion it can be said that, in the case of $^{158}$Gd, the agreement between the experimentally reduced transition probabilities and the predictions of adiabatic theory would be enhanced by using Michailov's formula (Ref. 12). More accurate values may be obtained by means of a microscopic model of octupole states of some even deformed nuclei, such as those proposed by Neergard and Vogel (Ref. 13), and by Kocbach and Vogel (Ref. 14).

## 4.2. Distribution of Beta-Strength.

The two-quasiparticle states of $^{158}$Gd can be calculated on the basis of the Nilsson model. These calculations have been performed using deformed oscillator potential, taking into account the $\ell^2$ term as well as pairing interactions (Ref. 16,17). The potentials, characterized by parameters $\varkappa$ and $\mu$, have been chosen according to Ref. 16; $\varkappa_p = 0.0637$ and $\mu_p = 0.60$ for protons; $\varkappa_n = 0.0637$ and $\mu_n = 0.47$ for neutrons. The following values were used for pairing force strength: $G_p = 20.8$ MeV/A for protons, and $G_n = 15.6$ MeV/A for neutrons. Both the quadrupole $\varepsilon$ and the hexadecapole $\varepsilon_4$ axially symmetrical deformations were accounted for. The values $\varepsilon = 0.24$ and $\varepsilon_4 = -0.026$ were used as suggested by Hendrie et al. (Ref. 18), who investigated deformation parameters by means of 50 MeV alpha-particle scattering.

Table V contains a list of those pure two-quasiparticla states predicted by the applied model (at energies below 2.6 MeV), having proper configurations owing to their direct feeding from the $^{158}$Eu ground state. For the ground state of $^{158}$Eu, the configuration of Nilsson model orbitals p/413/ $\downarrow$ and n/521/ $\uparrow$ was assumed, since the $^{159}$Gd nucleus has an add neutron with the ground state quantum numbers $3/2^-$ /413/. The transitions from the $^{158}$Eu ground state to $^{158}$Gd states listed in Table V may be: allowed hindered, frist forbidden unhindered, or unique. On the basis of available data on such transitions in the rare earth region (Ref. 19), we assumed 7, 7.5, and 8.5 respectively for their log ft values. For the allowed hindered transition proceeding between the orbitals n $3/2^-$ (521) and p $5/2^+$ (531), the lower value of 6.5 was assumed, in agreement with the experimental evidence and calculations for rare-earth nuclei presented by Fujita (Ref. 20).

It has been difficult to compare calculated pure two-quasiparticle states with the experiment because of the lack of complete experimental informations on spins, parities and deexcitation patterns. The primary difficulties were due to level mixing effects and the splitting of states caused by collective interactions. We have therefore analysed the distribution of the average beta intensity rather than the probabilites of individual transitions (Ref. 21). The energy range of observed $^{158}$Eu deexcitations has been divided into $\Delta E = 0.2$ MeV intervals and the beta strength

$$S = \frac{1}{\Delta E} \sum \frac{1}{ft}$$

has been calculated for each interval. The results are shown in Fig. 5. The low-energy beta intensity is caused by the ground state rotational band. The beta-feeding of the collective vibrational and octupole states is discernible in the energy interval 0.8 - 1.6 MeV. The two-quasiparticle levels start to appear above the energy gap (for neutrons, 1.63 MeV), which causes a pronounced rise in beta decay strength. The shape difference between the theoretical and experimental curves may be attributed to collective interactions which tend to split the two-quasiparticle states, and to our rather rough estimates of log ft values (refer to Table V). Above 1.6 MeV, the experimental beta strength is equal to 75 % of the theoretical value. If the beta transitions below 1.6 MeV are also accounted for, the total beta strength amounts to 92 % of that predicted theoretically. Since the accuracy of log ft values for weaker transitions is 10 - 20 %, the agreement between the theoretical and experimental values of beta strength appears to be satisfactory.

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# TABLE I

Energies and relative intensities of gamma rays observed in $^{158}$Eu decay

| γ-ray energy /keV/ | relative intensity | γ-ray energy /keV/ | relative intensity |
|---|---|---|---|
| 79.6 ± 0.2 | 46.4 ± 4.6 | 1141.7 ± 0.3 | 0.83 ± 0.08 |
| 182.1 ± 0.2 | 8.2 ± 1.4 | 1180.1 ± 0.3 | 0.90 ± 0.20 |
| 528.1 ± 0.2 | 6.1 ± 0.5 | 1183.8 ± 0.3 | 9.9 ± 0.9 |
| 606.6 ± 0.2 | 13.0 ± 0.6 | 1233.4 ± 0.3 | 0.69 ± 0.15 |
| 698.7 ± 0.2 | 4.0 ± 0.3 | 1260.4 ± 0.3 | 1.55 ± 0.20 |
| 743.3 ± 0.2 | 12.2 ± 0.9 | 1263.5 ± 0.2 | 7.50 ± 0.8 |
| 750.9 ± 0.3 | 0.82 ± 0.10 | 1283.7 ± 0.3 | 0.23 ± 0.05 |
| 764.0 ± 0.2 | 1.15 ± 0.16 | 1291.9 ± 0.3 | 0.96 ± 0.15 |
| 769.5 ± 0.2 | 1.9 ± 0.2 | 1300.8 ± 0.4 | 0.67 ± 0.07 |
| 779.1 ± 0.2 | 2.97 ± 0.25 | [illegible] ± 0.3 | 1.06 ± 0.26 |
| 816.5 ± 0.2 | 1.08 ± 0.09 | [illegible] | [illegible] |
| 824.3 ± 0.2 | 5.1 ± 0.4 | 1347.4 ± 0.3 | 5.9 ± 0.3 |
| 828.1 ± 0.3 | 0.85 ± 0.11 | 1433.1 ± 0.4 | 0.31 ± 0.12 |
| 852.6 ± 0.2 | 1.49 ± 0.10 | 1437.8 ± 0.4 | 0.17 ± 0.07 |
| 871.0 ± 0.2 | 5.1 ± 0.5 | 1520.4 ± 0.5 | 0.25 ± 0.08 |
| 897.9 ± 0.2 | 42.7 ± 1.9 | 1517.4 ± 0.5 | 0.12 ± 0.06 |
| 907.1 ± 0.2 | 6.0 ± 0.5 | 1713.4 ± 0.3 | 0.78 ± 0.10 |
| 917.0 ± 0.3 | 1.18 ± 0.14 | 1768.7 ± 0.4 | 8.22 ± 0.08 |
| 922.6 ± 0.2 | 5.9 ± 0.5 | 1849.3 ± 0.4 | 0.60 ± 0.15 |
| 925.7 ± 0.3 | 0.60 ± 0.15 | 1856.3 ± 0.5 | 0.56 ± 0.12 |
| 940.1 ± 0.3 | 1.2 ± 0.3 | [illegible] | [illegible] ± 0.3 |
| 944.3 ± 0.15 | 100 | 1929.8 ± 0.5 | 0.26 ± 0.08 |
| 953.4 ± 0.2 | 5.8 ± 0.5 | 1943.7 ± 0.3 | 4.8 ± 0.5 |
| 962.2 ± 0.2 | 6.0 ± 0.4 | 1957.1 ± 0.4 | 0.48 ± 0.10 |
| 977.0 ± 0.15 | 52.3 ± 2.1 | 1964.7 ± 0.3 | 0.47 ± 0.08 |
| 986.8 ± 0.2 | 4.9 ± 0.4 | 2022.8 ± [illegible] | [illegible] ± 0.2 |
| 999.1 ± 0.3 | 2.0 ± 0.2 | [illegible] | [illegible] |
| 1003.9 ± 0.3 | 1.78 ± 0.4 | 2314.4 ± 1.2 | 0.19 ± 0.10 |
| 1005.7 ± 0.3 | 4.5 ± 0.6 | 2366.1 ± 0.4 | 2.4 ± 0.5 |
| 1034.8 ± 0.3 | [illegible] ± 0.10 | [illegible] | 0.38 ± 0.10 |
| 1061.5 ± 0.3 | [illegible] ± 0.20 | 2446.9 ± [illegible] | 2.6 ± [illegible] |
| 1107.9 ± 0.2 | 18.6 ± 1.0 | | |
| 1116.0 ± 0.3 | 4.6 ± [illegible] | | |
| 1137.8 ± 0.4 | 0.62 ± [illegible] | | |

## TABLE II

### The values of log ft for the levels populated by $^{158}$Eu decay

| Energy level /keV/ | $\beta$ -feeding /%/ | log ft |
|---|---|---|
| 0 | 5 | 8.6 |
| 79.55 | 23.0 | 7.9 |
| 261.6 | 0.54 | 9.4 |
| 977.2 | 17.8 | 7.5 |
| 1023.8 | 21.4 | 7.3 |
| 1041.3 | 0.005 | - |
| 1187.1 | 1.96 | 8.3 |
| 1195.6 | 0.92 | 8.6 |
| 1260.4 | 0.77 | 8.6 |
| 1263.5 | 2.7 | 8.1 |
| 1265.5 | 0.15 | 9.3 |
| 1403.2 | 0.44 | 8.8 |
| 1517.4 | 0.07 | 9.4 |
| 1793.1 | 5.5 | 7.3 |
| 1848.1 | 2.5 | 7.6 |
| 1894.5 | 0.58 | 8.2 |
| 1930.0 | 6.1 | 7.1 |
| 1963.8 | 5.3 | 7.1 |
| 2023.8 | 2.6 | 7.4 |
| 2269.1 | 1.35 | 7.4 |
| 2324.8 | 2.5 | 7.0 |
| 2394.9 | 0.14 | 8.2 |
| 2446.3 | 1.2 | 7.1 |
| 2498.6 | 0.43 | 7.5 |

# TABLE III

Ratios of reduced transition probabilities for transitions from the octupole bands of $^{158}$Gd to the ground state rational band.

| Energy level (keV) | $\frac{I_i \rightarrow I_f}{I_i' \rightarrow I_f'}$ | Ki | Kf | Experimental value of B(L) ratios | Theoretical values of B(L) ratios | | | Michailov's parameter |
|---|---|---|---|---|---|---|---|---|
| | | | | | Alaga (11) | Michailov (12) | Kocbach Vogel (14) | |
| 977.2 | $\frac{1^- \rightarrow 0^+}{1^- \rightarrow 2^+}$ | 1 | 0 | 0.96 ± 0.08 | 2.0 | 0.83 | 1.8 | 0.01 |
| 1041.3 | $\frac{3^- \rightarrow 2^+}{3^- \rightarrow 4^+}$ | 1 | 0 | 1.07 ± 0.16 | 1.33 | 0.95 | 1.0 | |
| 1263.5 | $\frac{1^- \rightarrow 0^+}{1^- \rightarrow 2^+}$ | 0 | 0 | 0.623 ± 0.12 | 0.51 | 0.49 | 0.573 | -0.0091 |
| 1403.2 | $\frac{3^- \rightarrow 2^+}{3^- \rightarrow 4^+}$ | 0 | 0 | 0.74 ± 0.14 | 0.75 | 0.73 | 0.97 | |
| 1639.3 | $\frac{5^- \rightarrow 4^+}{5^- \rightarrow 6^+}$ | 0 | 0 | 1.44 ± 0.34*) | 0.833 | 0.80 | 1.32 | |

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*) Value taken from ref. (8)

## TABLE IV

Ratios of reduced transition probabilities for some $2^+$ states of $^{158}Gd$ to the $1^-$ octupole band and the ground state rotational band.

| Energy level (keV) | $\frac{I_i\rightarrow I_f}{I_i'\rightarrow I_f'}$ | $K_f$ | Experimental value | Theoretical values | | | | Michailov's parameter | Suggested $K_i$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Alaga (11) | | | Michailov (12) | | |
| | | | | $K_i=0$ | $K_i=1$ | $K_i=2$ | | | |
| 1793.1 | $\frac{2^+\rightarrow 1^-}{2^+\rightarrow 2^-}$ | 1 | 0.467 ± 0.10 | 0.2 | 1.8 | 1.83 | 0.565 | 0.11 | 2 |
| | $\frac{2^+\rightarrow 3^-}{2^+\rightarrow 2^-}$ | 1 | 0.44 ± 0.08 | 0.8 | 3.2 | 0.2 | 0.55 | | |
| 1963.8 | $\frac{2^+\rightarrow 0^+}{2^+\rightarrow 2^+}$ | 0 | 0.086 ± 0.020 | 0.7 | 2.8 | 0.7 | 0.112 | 0.1 | 2 |
| | $\frac{2^+\rightarrow 4^+}{2^+\rightarrow 2^+}$ | 0 | 0.20 ± 0.05 | 1.8 | 0.321 | 0.05 | 0.288 | | |
| | $\frac{2^+\rightarrow 3^-}{2^+\rightarrow 2^-}$ | 1 | 5.2 ± 1.7 | 0.8 | 3.2 | 0.2 | 7.5 | 0.642 | 2 |
| | $\frac{2^+\rightarrow 1^-}{2^+\rightarrow 2^-}$ | 1 | 3.6 ± 1.2 | 0.2 | 1.8 | 1.83 | 2.8 | | |
| 2.324.8 | $\frac{2^+\rightarrow 3^-}{2^+\rightarrow 2^-}$ | 1 | 0.36 ± 0.11 | 0.8 | 3.2 | 0.7 | 0.37 | -0.11 | 1 |
| | $\frac{2^+\rightarrow 1^-}{2^+\rightarrow 2^-}$ | 1 | 3.5 ± 0.5 | 0.2 | 1.8 | 0.467 | 3.7 | | |

## TABLE V

Two quasi-particle levels in $^{158}$Gd fed by beta-decay of $^{158}$Eu.

| Configuration | Energy (MeV) | Spin and parity | Log ft (assumed) |
|---|---|---|---|
| nn /521 ↑ + 642 ↑ / | 1.63 | $1^-$ | 7.0 |
| nn /521 ↑ + 523 ↓ / | 1.78 | $1^+$ | 7.5 |
| pp /413 ↓ + 411 ↑ / | 1.89 | $1^+$ | 7.5 |
| pp /413 ↓ + 532 ↑ / | 1.94 | $0^-$ | 6.5 |
| nn /521 ↑ + 651 ↑ / | 2.03 | $0^-$ | 7.0 |
| nn /521 ↑ + 633 ↑ / | 2.40 | $2^-$ | 7.0 |
| nn /521 ↑ + 521 ↓ / | 2.53 | $1^+$ | 8.5 |

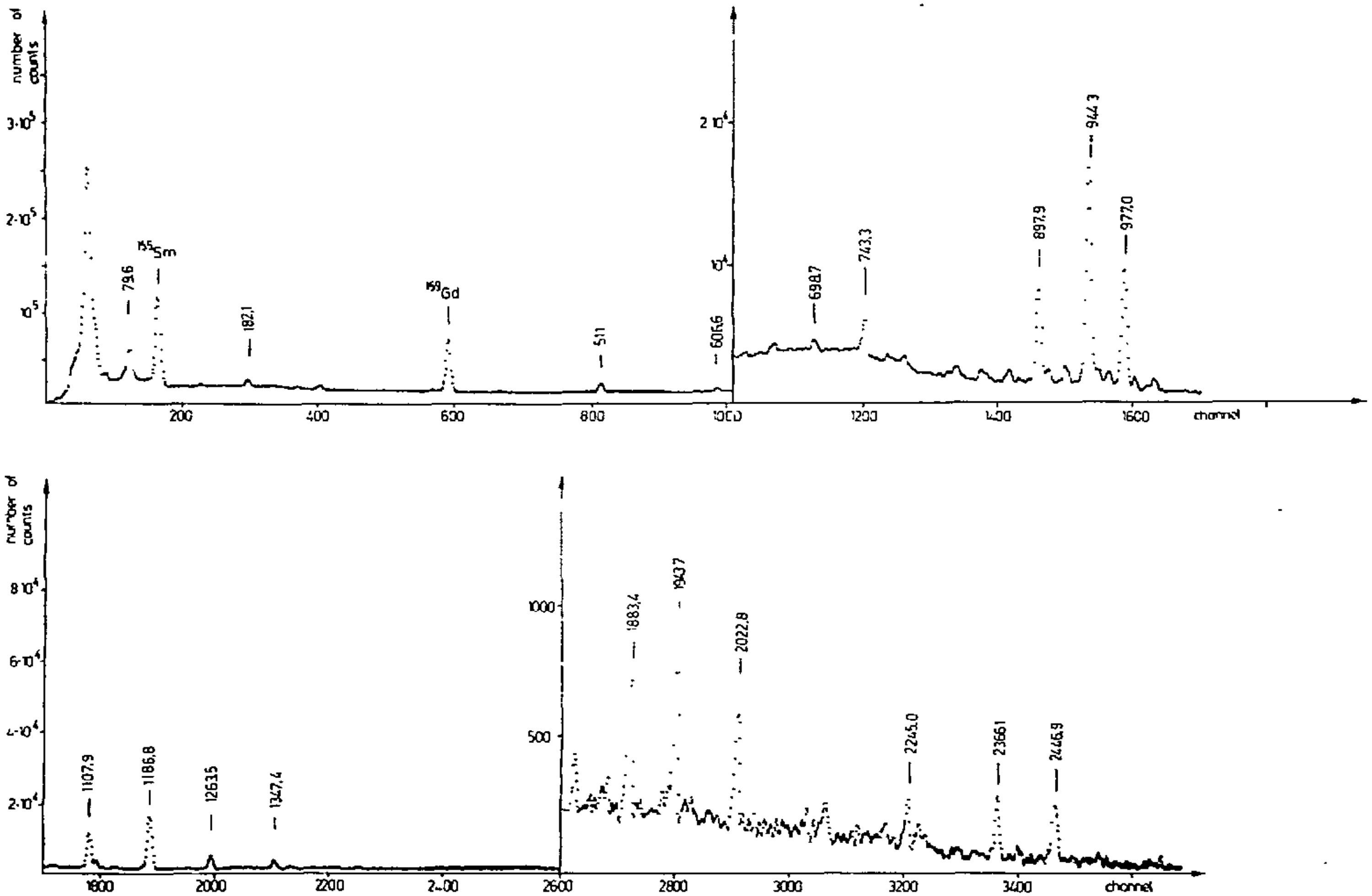

Fig.1. Gamma spectrum of $^{158}$Eu.

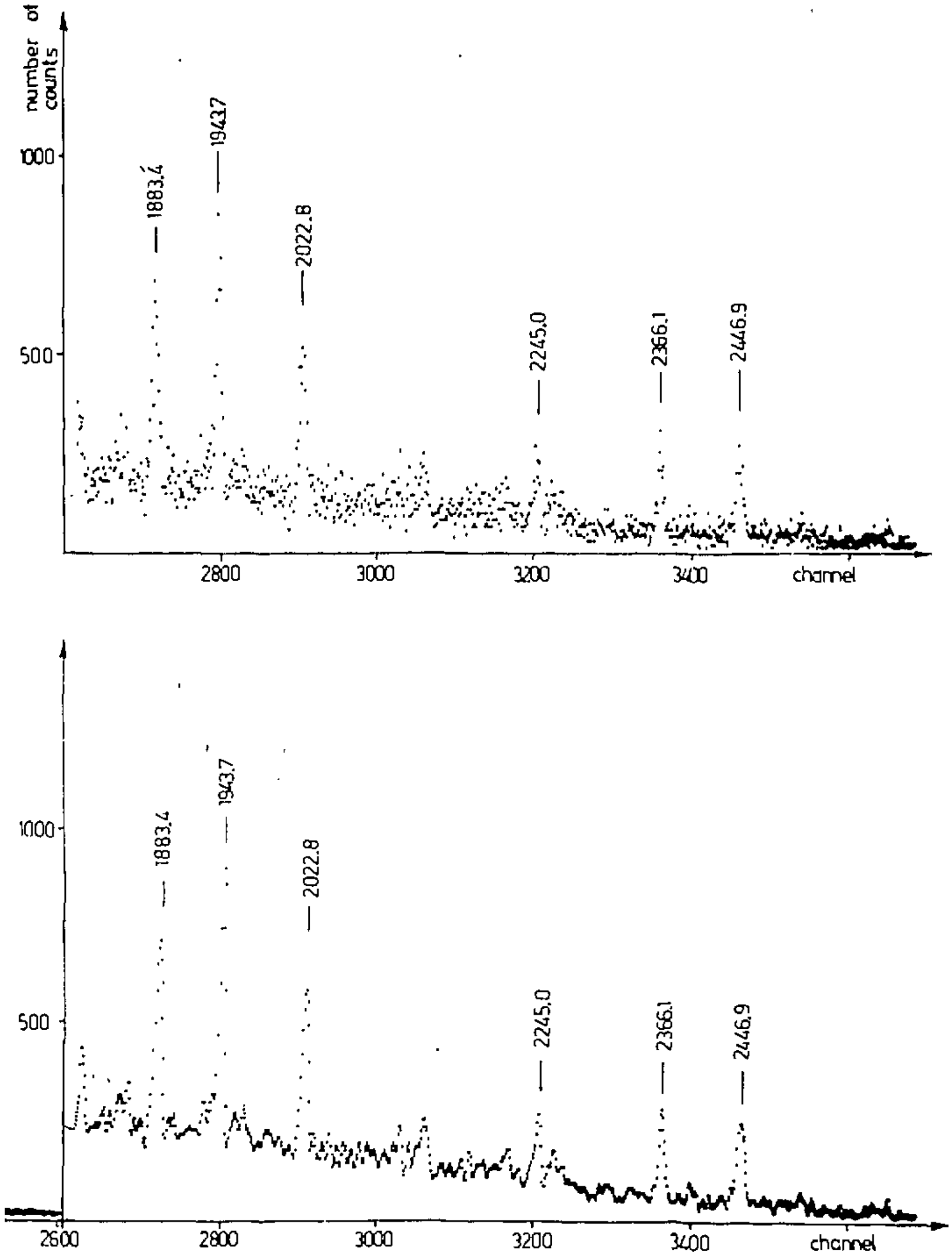

Fig.2. The fragment of gamma spectrum of $^{158}$Eu before and after the smoothing.

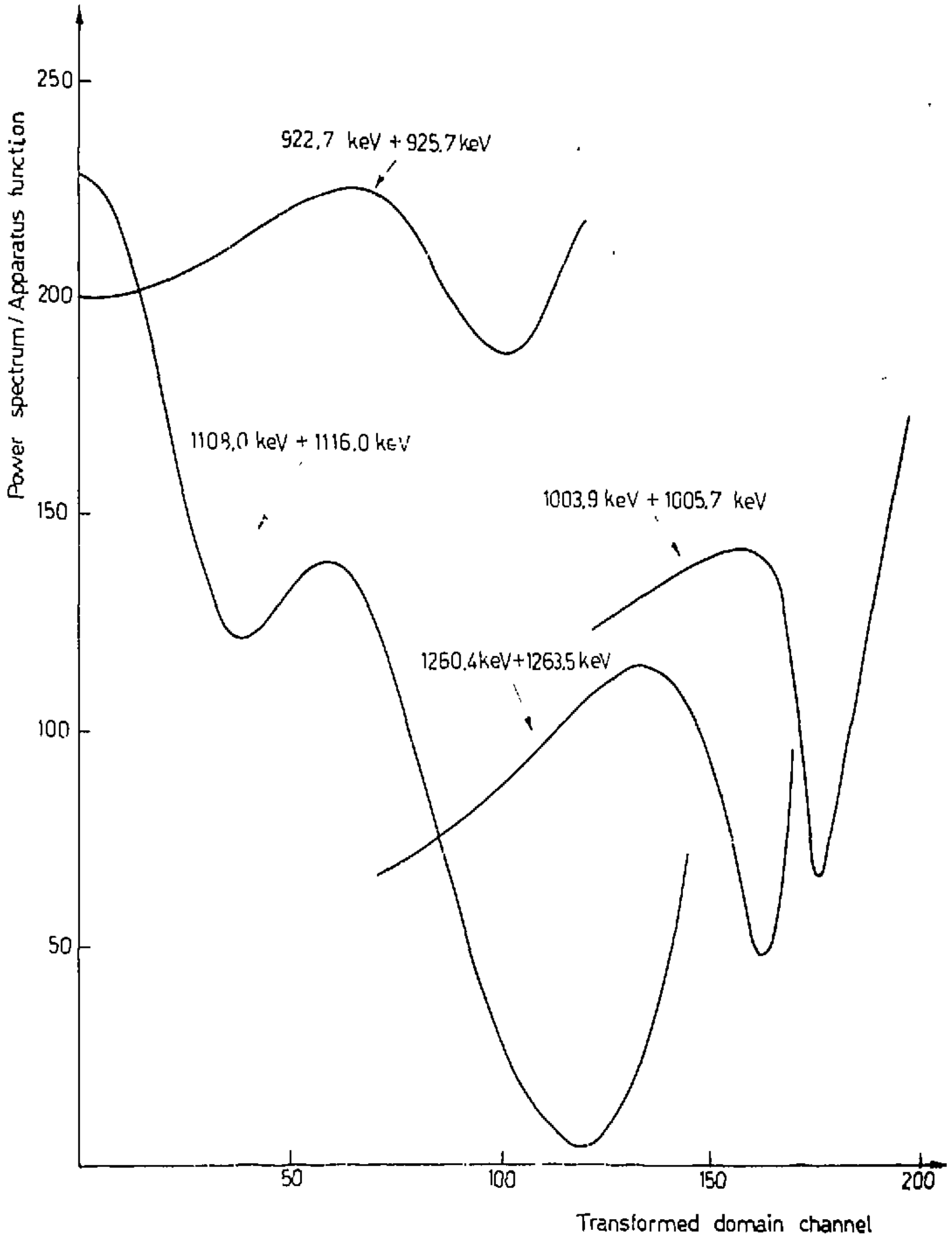

Fig 3 The resolution of double lines by means of Fourier transforms. The scale is arbitrary since only the amplitudes ratios are important.

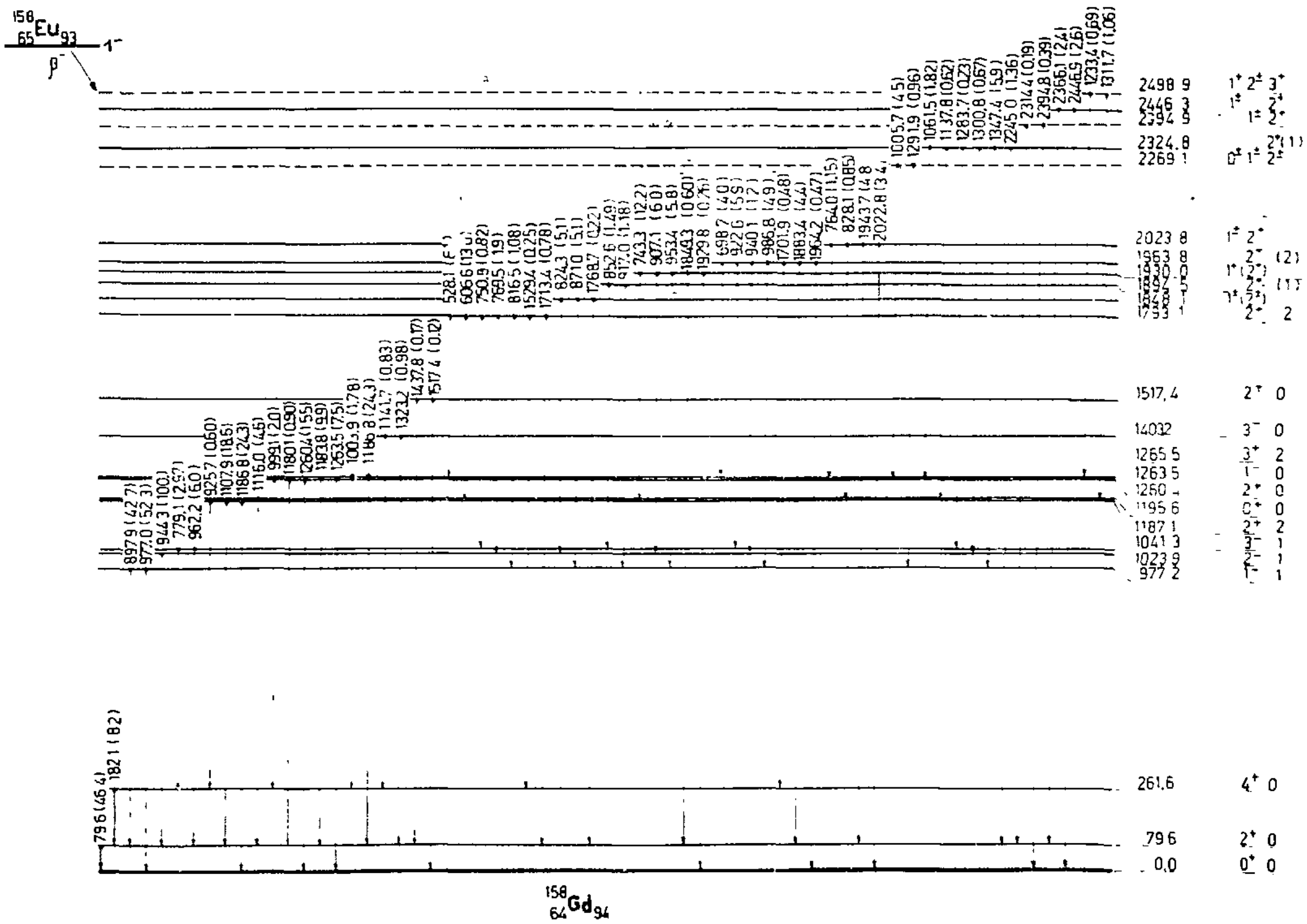

Fig. 4. The decay scheme of $^{158}$Eu

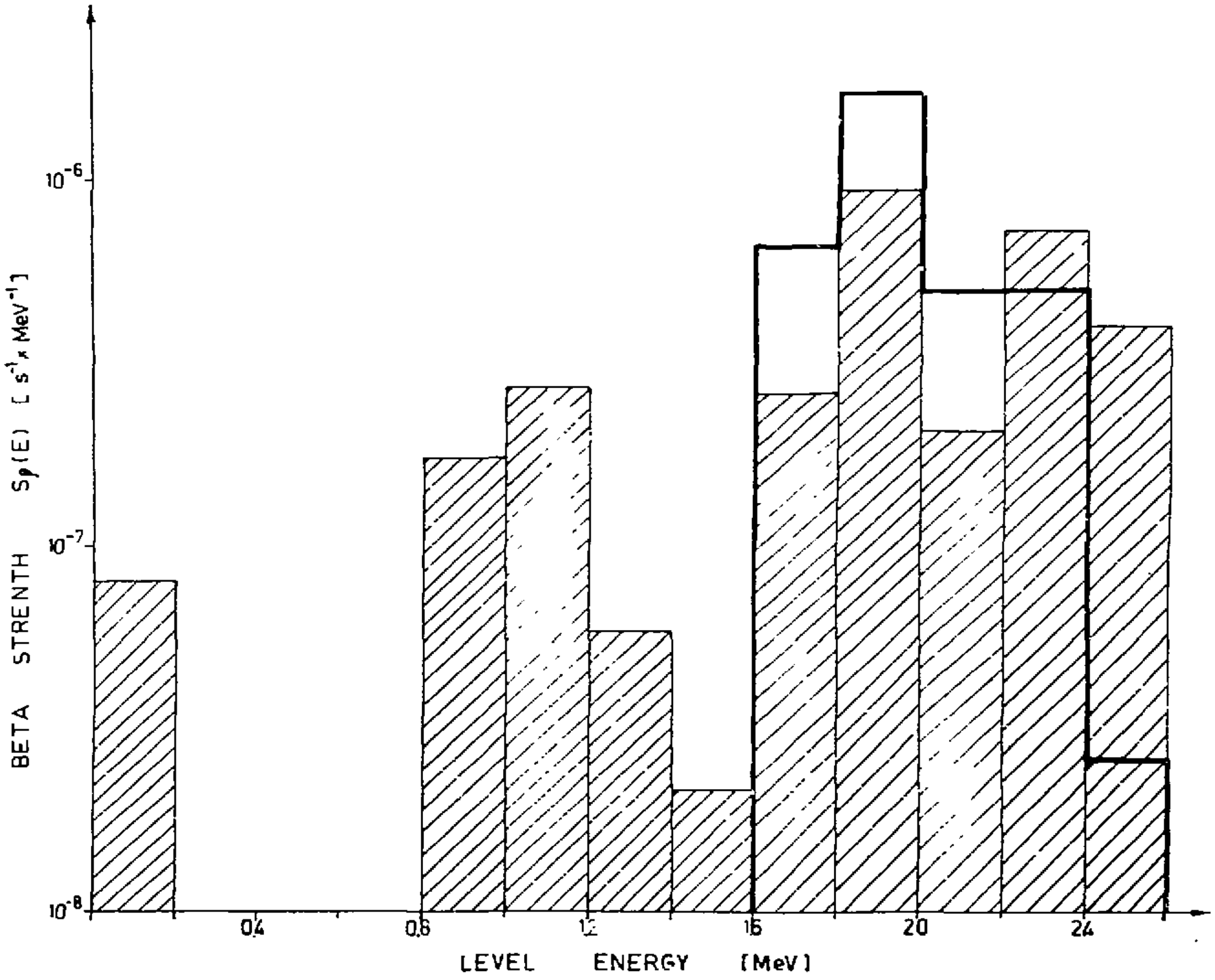

Fig. 5. Beta strength distribution for the $^{158}$Eu decay. Shaded area — experimental results, bold line theoretical calculations.

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