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GAMMA-GAMMA ANGULAR CORRELATIONS IN Re^{187}

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Abstract: Angular correlation measurements have been made on the 72 keV-134 keV and 552 keV-134 keV gamma-ray cascades in Re^{187} following the decay of 24 h W^{187}. The observed correlation functions are $W(\theta) = (1 \pm 0.004) - (0.047 \pm 0.024) P_2(\cos \theta) + (0.004 \pm 0.041) P_4(\cos \theta)$ and $W(\theta) = (1 \pm 0.006) - (0.034 \pm 0.017) P_2(\cos \theta) - (0.007 \pm 0.030) P_4(\cos \theta)$, respectively, for the two cascades. The results are consistent with the spin values $\frac{9}{2}$ and $\frac{5}{2}$ for the excited energy levels at 206 keV and 686 keV, respectively. The above correlation functions are considerably different from those reported by Behrend and Neuert [1]) for the 72 keV-134 keV cascade and by Arns and Wiedenbeck [2]) for the 552 keV-134 keV cascade.

1. Introduction

Spin and parity of the excited states of the Re^{187} nucleus have been the subject of several investigations [1-6]). The beta decay of W^{187} yields sufficient energy to populate levels in the daughter nucleus up to some 1300 keV. The internal conversion coefficients of the gamma rays following beta decay were studied by Vergnes [3]), Gallagher *et al.* [4]) and Edwards and Boehm [5]). To the level at 206 keV these authors assign spin $\frac{9}{2}$ and odd parity. By measuring the angular correlation of the 72 keV-134 keV cascade Behrend and Neuert [1]), however, obtained spin $\frac{3}{2}$, whereas Klimentovskaya and Shavrin [6]) using this method found extensive agreement with the conversion measurements. For the 686 keV level Vergnes and Gallagher *et al.* reported spin and parity $\frac{5}{2}^-$. Arns and Wiedenbeck [2]) investigated the angular correlation of the 552 keV-134 keV cascade and obtained a strong positive anisotropy. The measured correlation function is only consistent with a spin assignment of $\frac{7}{2}$ to the excited state at 686 keV. For the same cascade Gallagher *et al.* found isotropy to within 1 %. Klimentovskaya and Shavrin observed a weak positive anisotropy.

Under such circumstances it was felt useful to re-examine the angular correlation of the 72 keV-134 keV and 552 keV-134 keV cascades.

2. Experimental Procedure

The main features of the equipment have been described in a previous paper [7]). Angular correlation data were taken in a double quadrant sequence. A least-squares fit of the data was made to the function

$$W(\theta) = \sum_{\nu} A_{2\nu} P_{2\nu}(\cos \theta). \tag{1}$$

The expansion coefficients were corrected for geometrical effects and interactions in the source by a numerical method [8]).

Sources were prepared from tungsten powder of 99.98 % purity and irradiated in the Karlsruhe research reactor. The powder was dissolved by means of a mixture of 40 % hydrofluoric acid and concentrated nitric acid. The compounds WF_6 and WOF_4 formed during this process were converted into pertungstic acid of the probable composition WO_3-H_2O_2 by extensive fuming off and repeated addition of some drops of perhydrol. Concentrated sulfuric acid was used to precipitate tungstic acid hydrate WO_3-$2H_2O$ from this solution. When produced in this way the hydrate reacts easily with about 20 % hydrofluoric acid and forms a stable solution.

The gamma ray spectrum was followed for a period of several weeks. No impurity activities were found to be present in the sources. In order to avoid interferences from the very small amount of long-lived W^{181} contained all data were taken early in the decay of each source.

3. Results

3.1. ANGULAR CORRELATION OF THE 72 keV-134 keV CASCADE

Evaluation of the experimental data yielded the angular correlation function

$$W(\theta) = (1 \pm 0.004) - (0.023 \pm 0.010) P_2(\cos\theta) + (0.002 \pm 0.019) P_4(\cos\theta). \quad (2)$$

Due to the complex level structure of Re^{187} this result has still to be corrected. Interfering coincidences are recorded in particular between the 134 keV gamma ray and

(1) 61 keV conversion quanta of the 72 keV transition,

(2) 552 keV photons producing Compton electrons with an energy of 72 keV,

(3) 61 keV photons from the K-conversion of the 552 keV transition, as well as between 134 keV Compton electrons of the 552 keV gamma ray and

(4) 61 keV conversion quanta of the 134 keV radiation.

An estimate of the share of possible interfering coincidences passing through the metastable state at 206 keV showed that contributions of this type are negligible because of the effective resolving time of 6 nsec used in the experiments. The K-conversion coefficient for the 72 keV transition as observed by Gallagher *et al.* [4]) is 1.01 ± 0.14. This value is in good agreement with the result found by Edwards and Boehm [5]). If the number of true coincidences of the 72-keV-134 keV cascade is assumed to be 100 %, then, taking into account the fluorescence yield and the iodine K X-ray escape probability, for item (1) an interference of 93 ± 15 % is obtained. The shares of items (2)-(4) were estimated to be 1.0 ± 0.3 %, 0.7 ± 0.2 % and 1.8 ± 0.7 %, respectively. With the exception of contribution (2) all interfering coincidences have an isotropic angular correlation. The anisotropy resulting from item (2) can be neglected (cf. subsect. 3.2). The corrected angular correlation function is thus given by

$$W(\theta) = (1 \pm 0.004) - (0.047 \pm 0.024) P_2(\cos\theta) + (0.004 \pm 0.041) P_4(\cos\theta). \quad (3)$$

The ground state spin of Re^{187} has been measured to be [9,10] $\frac{5}{2}$. The first excited state at 134 keV may be characterized as the first rotational excitation of the ground state configuration [1-6,11] and therefore will have a spin of $\frac{7}{2}$. If these spin assignments

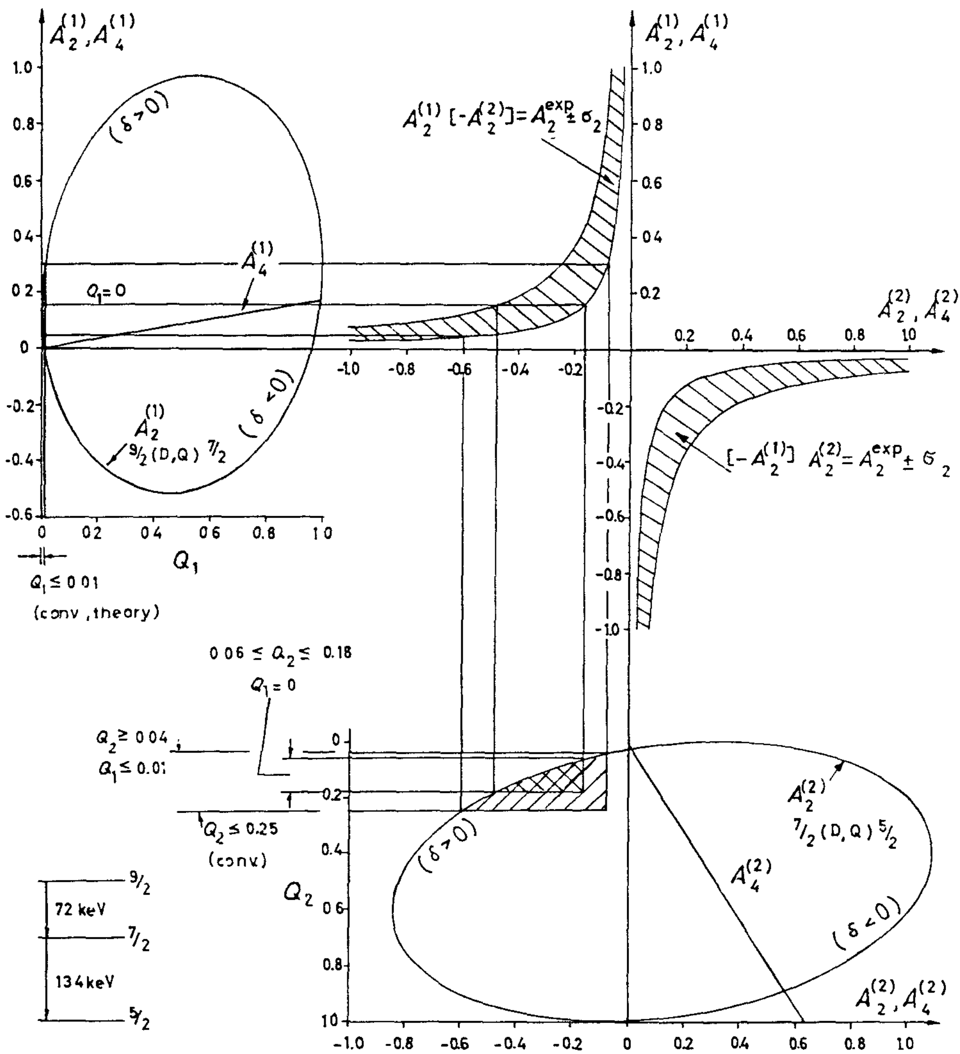

Fig. 1. Analysis of the 72 keV-134 keV angular correlation in terms of a $\frac{9}{2}(1,2)\,\frac{7}{2}(1,2)\,\frac{5}{2}$ spin sequence.

are correct, then the result given in eq. (3) is consistent with the cascade $\frac{9}{2}(1,2)$ $\frac{7}{2}(1,2)$ $\frac{5}{2}$. Fig. 1 shows the analysis of eq. (3) in terms of this spin sequence. Starting from the assumption that the 72 keV transition is pure dipole radiation the limits of error will allow a quadrupole content $0.06 \leqq Q_2 \leqq 0.18$ in the 134 keV transition. All conversion data reported till now agree in stating that certainly $Q_2 \leqq 0.25$.

The conversion measurements as well as theoretical considerations (cf. sect. 4) furthermore indicate that $Q_1 < 0.01$. As is shown in fig. 1 the observed angular correlation function can be interpreted in agreement with these results by the cascade $\frac{9}{2}(Q_1 \leqq 0.01)\ \frac{7}{2}(0.04 \leqq Q_2 \leqq 0.25)\frac{5}{2}$.

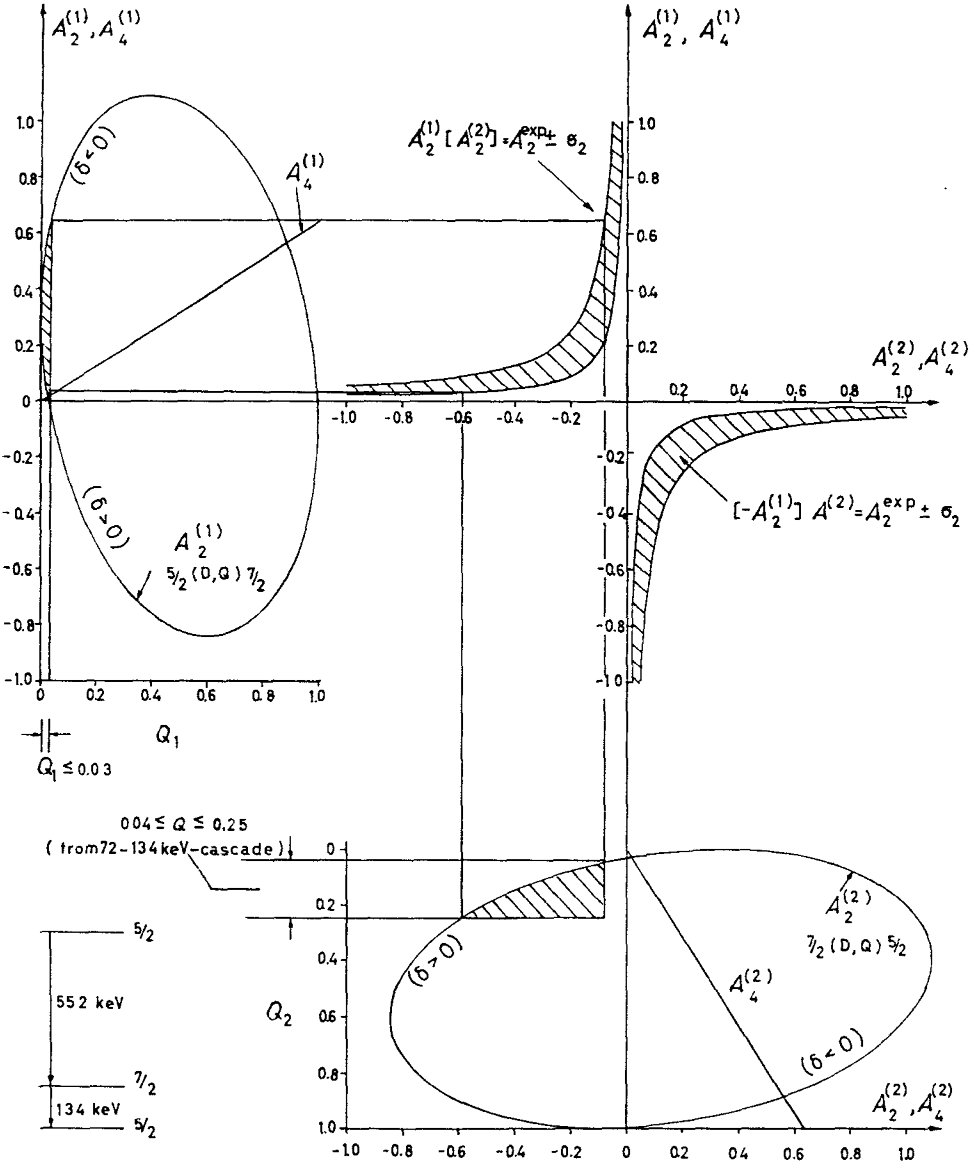

Fig. 2. Analysis of the 552 keV-134 keV angular correlation in terms of a $\frac{9}{2}(1, 2)\ \frac{7}{2}(1, 2)$ $\frac{5}{2}$ spin sequence.

Because of the short half life of the 134 keV excited state ($\tau_{\frac{1}{2}} = 1.04 \times 10^{-11}$ sec, cf. ref. [12]) an attenuation of the angular correlation is unlikely. The above statements therefore refer to the true correlation.

3.2. ANGULAR CORRELATION OF THE 552 keV-134 keV CASCADE

The angular correlation function was found to be

$$W(\theta) = (1 \pm 0.006) - (0.034 \pm 0.017)P_2(\cos\theta) - (0.007 \pm 0.030)P_4(\cos\theta). \tag{4}$$

This result is consistent with a spin $\frac{5}{2}$ for the excited state at 686 keV. Fig. 2 shows the graphical analysis of eq. (4) in terms of a $\frac{5}{2}(1,2)\,\frac{7}{2}(1,2)\frac{5}{2}$ spin sequence. When using the result $0.04 \leqq Q_2 \leqq 0.25$ from subsect. 3.1 the quadrupole content of the 552 keV transition is $Q_1 \leqq 0.03$. Conversion data indicate that $Q_1 \leqq 0.01$.

4. Discussion

Behrend and Neuert [1]) obtained the angular correlation function $W(\theta) = (1 \pm 0.008) - (0.229 \pm 0.033)P_2(\cos\theta) + (0.091 \pm 0.045)P_4(\cos\theta)$ for the 72 keV-134 keV cascade. Comparison with eq. (3) thus shows a distinct discrepancy. If the result of these authors is re-interpreted in terms of a $\frac{9}{2}(1,2)\,\frac{7}{2}(1,2)\,\frac{5}{2}$ spin sequence assuming $Q_2 \leqq 0.25$, the quadrupole admixture of the 72 keV transition is found to be $Q_1 \geqq 0.02$, which is inconsistent with the conversion data. The result $Q_1 \leqq 0.01$ is consistent with a theoretical estimate of the quadrupole content. If $B(L, J_i \rightarrow J_f)/B(L, J_i \rightarrow J_{f'})$ represents the ratio of reduced transition probabilities for transitions of multipole order L de-exciting a state to two states of the same rotational band, then [13])

$$\frac{B(L, J_i \rightarrow J_f)}{B(L, J_i \rightarrow J_{f'})} = \frac{|(J_i L K_i K_f - K_i | J_i L J_f K_f)|^2}{|(J_i L K_i K_f - K_i | J_i L J_{f'} K_f)|^2}, \tag{5}$$

where K_i and K_f ($K_i + K_f \geqq L$) are the z components of the initial and final total angular momenta J_i, J_f and $J_{f'}$, respectively, and the brackets on the right side denote the Clebsch-Gordan coefficients. Eq. (5) yields $B(2, \frac{9}{2} \rightarrow \frac{7}{2})/B(2, \frac{9}{2} \rightarrow \frac{5}{2}) = 0.485$ for the 72 keV transition and the 206 keV direct decay to the ground state. From this value and the transition intensities derived from table 2 of ref. [11]) the quadrupole admixture Q_1 is found to be about 4×10^{-4}. Behrend and Neuert used a spherical source of tungsten oxide (W_2O_3) with 1 mm diameter. Probably the stronger anisotropy is at least in part due to absorption effects in the source.

The angular correlation given in eq. (4) for the 552 keV-134 keV cascade considerably deviates from the result obtained by Arns and Wiedenbeck [2]). According to these authors the following function is valid: $W(\theta) = 1 + (0.316 \pm 0.018)P_2(\cos\theta) - (0.086 \pm 0.027)P_4(\cos\theta)$. The negative A_4 coefficient implies a spin of $\frac{7}{2}$ for the 686 keV level. The log ft value 6.5 of the beta transition to this level then rules out the first two of the spin values $\frac{1}{2}^-$, $\frac{3}{2}^-$ or $\frac{7}{2}^-$ which the Nilsson model predicts for the ground state of W^{187}. However, spin $\frac{7}{2}^-$ of W^{187} would require noticeable beta transitions to the excited levels at 134 keV and 206 keV. The fact that these transitions cannot be observed as well as the agreement of our result with that of Gallagher *et al.* [4]) are in favour of the correctness of eq. (4).

A discussion and theoretical interpretation of the level structure of Re^{187} is given elsewhere [11]).

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