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On the Decay of ^{148}Pm

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The β-γ directional correlation between the 1,930 keV β-group and the 511 keV cascade γ-ray in the 5.4 d ^{148}Pm decay has been measured at 14 different γ-energy points. The anisotropy is found to be positive and is $(4.4 \pm 0.4)\%$ at 1,210 keV. The energies of the γ-rays depopulating the levels in ^{148}Sm have been measured using a Ge(Li) spectrometer with an accuracy of better than 1 keV. The γ-ray intensities have been determined within 15%.

1. Introduction

The 1,930 keV β-transition from the ground state of ^{148}Pm to the first excited state in ^{148}Sm (see Fig. 1) might be expected to exhibit the typical features of a transition described by the ξ-approximation[1] since the Coulomb factor $\xi = \alpha Z/2R$ is about three times larger than the end-point energy $W_0(\mathrm{mc}^2)$ (i.e., $\xi \approx 13.4$ and $W_0 = 4.7$). However, the $\log ft$ value (≈ 9.4) is somewhat higher than what is usually found for a non-unique first-forbidden transition. This suggests that the ordinarily predominating matrix elements for a $\Delta J = 1$ first-forbidden decay $\langle i\boldsymbol{r}\rangle$ and $\langle \sigma \times \boldsymbol{r}\rangle$ might be reduced by either a nuclear selection rule or by cancellation. In either case, the directional correlation between the β-rays and the cascade γ-rays should show a deviation from the $W^2 - 1/W$ energy dependence typical for the ξ-approximation.

When Baba, Ewan and Suarez[2] studied the spectrum shape factor of the outer 2,480 keV β-transition in ^{148}Pm, they concluded that both cancellation and selection rule effects were operative. They ascribed the equally large $\log ft$ value (≈ 9.2) of this transition to a reduction in size of the nuclear matrix elements and the large deviation from statistical shape to a cancellation of the matrix elements. The same authors performed a β-γ directional correlation experiment on the 1,930 keV β-500 keV γ-cascade and report an anisotropy of less than 6% for an

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1 Kotani, T., Ross, M. H.: Phys. Rev. 113, 662 (1959).

2 Baba, C. V. K., Ewan, G. T., Suarez, J. F.: Nucl. Phys. 43, 264 (1963).

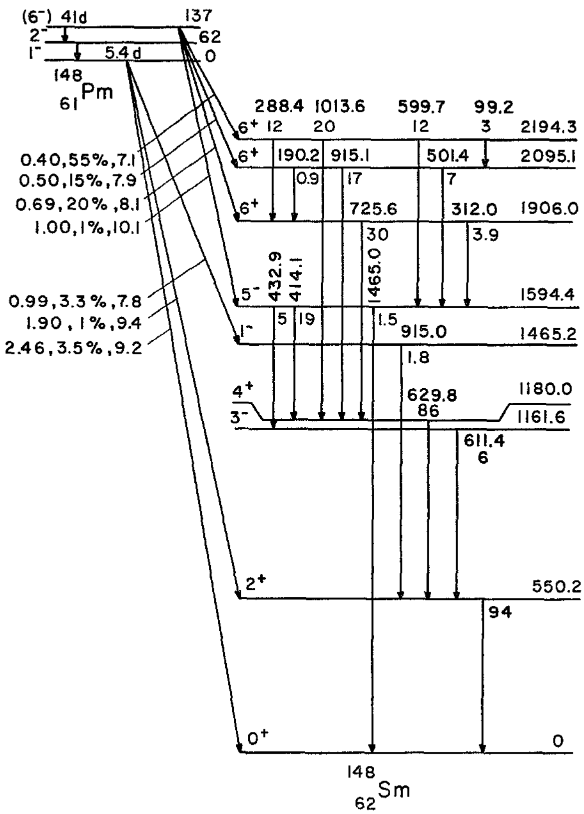

Fig. 1. Decay scheme of 41 d ^{148}Pm. The numbers on the β-transition are energy (keV), intensity (% per decay) and logft value. The γ-transitions are labeled by their energy (keV) and intensity (% per decay). In constructing the decay scheme, the results of previous investigations have been used and are discussed in the text

integral measurement. From this they conclude that the 1,930 keV β-group is not unique in character and infer a spin of 1 to the ^{148}Pm ground state. A later measurement by Nainan and Moore[3] indicated a large negative anisotropy, while a measurement by Wyly, Patronis and Braden[4] shows a small positive anisotropy. A recent measurement by Amadori, Gupta and Sastry[5] on the same cascade also shows a positive anisotropy. Our measurements are in good agreement with those in Refs.[4,5] and definitely rule out a negative anisotropy. There is, however, an indication that the ξ-approximation does not adequately describe this $1^-(\beta)\,2^+(\gamma)\,0^+$ cascade. A measurement of the γ-spectrum of the

3 Nainan, T. D., Moore, S. E.: Nucl. Phys. A **94**, 257 (1967).
4 Wyly, L. D., Patronis, E. T., Jr., Braden, C. H.: Phys. Rev. **172**, 1153 (1968).
5 Amadori, R. A., Gupta, N. K., Sastry, K. S. R.: Nucl. Phys. A **118**, 33 (1968).

^{148}Pm decay using a Ge(Li) detector confirms the decay scheme established by Baba *et al.*[2] from their study of the internal conversion electron spectrum.

2. Source Preparation and Experimental Procedure

The ^{148}Pm sources were prepared by two methods: (i) Proton bombardment of ^{148}Nd (enriched to 82%). The ^{148}Nd(p, n) ^{148}Pm reaction was performed at the Oak Ridge Cyclotron Laboratory. The ^{148}Pm activity was then separated from the target in a cation-exchange resin-column. (ii) Thermal neutron irradiation of ^{147}Pm. Carrier-free ^{147}Pm (half-life 2.5 y) was irradiated with thermal neutrons in batches of 5 mCi for periods of 6 days in a flux of $2 \cdot 10^{13}$ n/cm^2 sec. Each irradiation yielded about 0.5 mCi of ^{148}Pm. No observable amount of ^{149}Pm was produced by double neutron capture.

The ratio of the 5.4 to the 41 d (isomeric) activity was approximately 2:1. However, as can be seen from the decay scheme in Fig. 1, the isomeric decay is not expected to interfere with the angular correlation measurement on the cascade of interest in the ground-state decay.

Working samples of the radioactive material were deposited on 6.4 μm mylar film which was supported by an aluminium ring with a diameter of 2.54 cm. The source thickness was not critical because of the high energy (>800 keV) of the negatons investigated. It is conservatively estimated that the source thickness was less than 0.2 mg/cm^2.

Energy and intensity measurements were performed on the γ-transitions with a $4\,\text{cm}^2 \times 0.5$ cm Ge(Li) spectrometer. Corrections were made for non-linearities in the spectrometer system and for the detector efficiency[6]. The spectrometer was calibrated with ^{88}Y and ^{22}Na before and after each run.

The directional correlation measurements were made with an automated β-γ scintillation coincidence spectrometer described elsewhere[7]. A zero cross-over timing circuit was operated at a coincidence resolving time of 30 nsec. Simultaneous measurement of the correlation for different β-energies was made by use of a multi-channel analyser. At the same time, an additional single-channel analyser-coincidence unit was used to measure the angular correlation with a β-energy window of 200 keV using a different average β-energy setting for each run. This procedure provided a cross check on the performance of the gating circuit of the analyser and a confirmation of the energy variation of the angular correlation as calculated from the multi-channel data.

6 Donnelly, K. P., Baer, H. W., Reidy, J. J., Wiedenbeck, M. L.: Nucl. Instr. **57**, 219 (1967).

7 Fischbeck, H. J., Newsome, R. W., Jr.: Phys. Rev. **129**, 2231 (1963).

A total of 24 measurements were carried out on three different ^{148}Pm sources. The total number of true coincidences ranged from $1.2 \cdot 10^5$ to $1.2 \cdot 10^4$ per angle per energy point of the energy range investigated. The ratio of true-to-chance counts varied from 2 to 24 depending on the initial source strength. A check measurement of the performance of the apparatus was performed using the allowed 606 keV β-364 keV γ-cascade in ^{131}I and the first-forbidden 2,410 keV β- 559 keV γ-cascade in ^{76}As. The measurement on ^{131}I gave an isotropic correlation within $\pm 0.05\%$. The results of the measurement on ^{76}As as a function of energy in Table 1 are in good agreement with previous measurements [7,8].

Table 1. *Results of the control measurement of the β-γ angular correlation coefficient A_2 between the first-forbidden 2410 keV β-group and the 559 keV cascade γ-ray in ^{76}As*

E_β (keV)	A_2		
	Present work	Ref. [7]	Ref. [8]
1,700	0.085 ± 0.007	0.087 ± 0.004	0.087 ± 0.007
1,900	0.088 ± 0.007	0.091 ± 0.004	0.097 ± 0.005
2,000	0.095 ± 0.007	0.101 ± 0.005	0.105 ± 0.006

3. Decay Scheme

The decay scheme of ^{148}Pm has been investigated several times [2,9-11]. However, since the question of interference is of considerable importance in the measurement of a small angular correlation, it was considered desirable to observe the γ-spectrum of the correlation sources with a high-resolution Ge(Li) spectrometer. The γ-ray energies and intensities observed in the 41 d decay of ^{148}Pm during the course of this work are given in Table 2 as well as the earlier results from Ref. [2]. The internal conversion coefficients and the quantum characteristics of the levels were taken from Ref. [2] to supplement the information obtained from the photon spectrum. The γ-intensities are normalized so that the total intensity of the 550 keV transition* is 95% and the β-intensities are deduced [2]. The energies of the β-groups from the isomeric level are calculated from the level energies of ^{148}Sm by taking the end-point of

* Assuming that the 550 keV transition is $E2$ and has the theoretical K-conversion coefficient $\alpha_K = 0.0083$.

8 Raghavan, R. S., Grabowski, Z. W., Steffen, R. M.: Phys. Rev. **139**, B1 (1965).
9 Nuclear Data Sheets, compiled by K. Way et al. (National Academy of Sciences, Washington, D.C.) NRC 61-4-64.
10 Harpster, J. W., Casper, K. J.: Nucl. Phys. **52**, 497 (1964).
11 Kenefick, R. A., Sheline, R. K.: Phys. Rev. **133**, B25 (1964).

Table 2. *Transition energies and relative intensities per decay observed in the 41 d ^{148}Pm decay. The intensities of this work are normalized so that the total intensity of the 550 keV transition is 95 per 100 disintegrations. The values of Ref.* [2] *are included for comparison*

Present work		Baba *et al.*[2]		
E_γ (keV)	I_γ ($\pm 15\%$)	E_γ (keV)	I_γ	deduced
75.9 ± 0.6	0.9	76	1.7 ± 0.5	
99.2 ± 0.6	3.0	99	3.4 ± 0.8	
190.2 ± 0.6	0.9	189	1.5	
288.4 ± 0.6	12	289	16 ± 3	12.5
312.0 ± 0.6	3.9	312	16 ± 3	2.8
414.1 ± 0.3	19	413	24 ± 4	17
432.9 ± 0.1	5.0	433	24 ± 4	5.7
501.4 ± 0.1	7.0	502	105 ± 15	6.7
550.2 ± 0.3	94.2	551	105 ± 15	95
599.7 ± 0.1	12	602	100	8
611.4 ± 0.1	6.0	611	100	6
629.8 ± 0.3	86.0	630	100	87
725.6 ± 0.1	30	727	38 ± 7	
915.1 ± 0.3	19	916	22 ± 4	
1,013.6 ± 0.3	20	1,015	21 ± 4	
1,465.2 ± 0.6	1.5	1,465	2.5 ± 1	

the innermost group to be 400 keV, which according to Ref.[2] is their best measured β-decay energy.

4. Directional Correlation

The β-γ directional correlation was measured as a function of the β-energy in the range from 820 to 1,590 keV. Inspection of the decay scheme (Fig. 1) shows that there should be no interference from either a γ-γ coincidence background or from another β-γ cascade for β-energies above 1,000 keV. This absence of interference was experimentally confirmed by the linearity of the Fermi-Kurie plot obtained from the angular correlation data (Fig. 2) and by the lack of any measurable γ-γ coincidence background when the β detector was shielded by an aluminium absorber from the β-radiation. Only for the points below 940 keV was it possible to obtain a measurable photon coincidence background. The photon coincidences in the region below 940 keV were less than 5% of the β-γ coincidence counts.

The results of the directional correlation measurement corrected for finite solid angle effects are summarized in Table 3. The coefficient A_2 is defined by the angular correlation function. $W(\theta) = 1 + A_2 P_2(\cos\theta)$. Also given in Table 3 is the reduced correlation coefficient

$$\varepsilon = A_2 W/W^2 - 1.$$

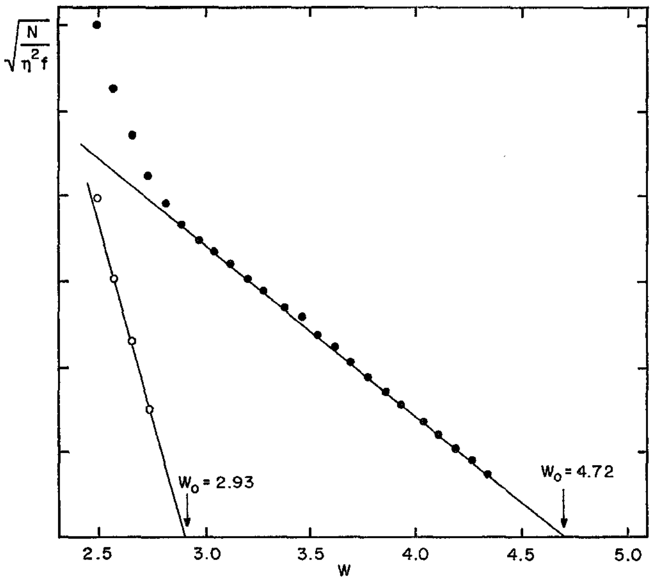

Fig. 2. Fermi-Kurie plot for the 1.90 MeV $1^- \to 2^+$ transition and 0.99 MeV $1^- \to 1^-$ transition in the 5.4 d decay of ^{148}Pm

Table 3. *Summary of the ^{148}Pm β-γ correlation data. The values marked (S) were taken with a single-channel analyser. (See text)*

$W(m_0 c^2)$	A_2	$\varepsilon = A_2 \frac{W}{W^2 - 1}$
2.60	0.050 ± 0.003 (S)	0.0223 ± 0.0013
2.77	0.042 ± 0.003	0.0174 ± 0.0012
2.84	0.041 ± 0.009 (S)	0.0165 ± 0.0036
2.98	0.036 ± 0.002	0.0136 ± 0.0008
3.00	0.036 ± 0.009 (S)	0.0135 ± 0.0034
3.18	0.036 ± 0.006	0.0127 ± 0.0020
3.38	0.029 ± 0.003	0.0099 ± 0.0010
3.39	0.035 ± 0.006	0.0114 ± 0.0019
3.59	0.012 ± 0.007	0.0036 ± 0.0021
3.74	0.019 ± 0.005	0.0055 ± 0.0014
3.78	0.020 ± 0.007 (S)	0.0057 ± 0.0020
3.90	0.009 ± 0.006	0.0025 ± 0.0017
4.08	0.017 ± 0.008 (S)	0.0044 ± 0.0021
4.30	0.004 ± 0.017	0.0010 ± 0.0042

This coefficient should be essentially energy independent if the ξ-approximation is valid. A χ^2 minimization was used to investigate a possible energy dependence of ε in the energy region above 1 MeV. Excluding therefore, any possible interference from the next inner group

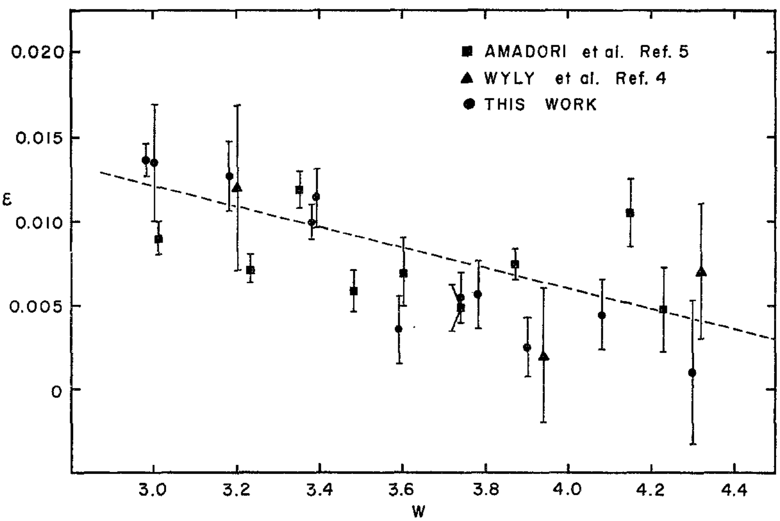

Fig. 3. Plot of the reduced angular correlation coefficient ε as a function of the β-energy W. The straight line represents a best fit to the data points

or photon-coincidence background. The data were fitted to an empirical expression of the form $\varepsilon = a + bW + cW^2$. The best fit was obtained for $a = 0.045$, $b = 0.011$, $c = 0$ with a $\chi^2 = 6.6$ and a confidence level of 0.5. It is interesting to note that the assumption that ε should be energy independent gave a rather poor fit, $\varepsilon = 0.0095 \pm 0.0013$ with a $\chi^2 = 77$. The unweighted average of our data, however, gives $\varepsilon = 0.0076$ which is in good agreement with Refs.[4,5] both of which find an average value of $\varepsilon = 0.007$.

In Fig. 3 we have plotted the results of our measurement together with those of Refs.[4,5]. It can be seen that the agreement between the measurements is reasonable. The possibility of an energy-dependent reduced correlation coefficient, however, cannot be ruled out. An attempt to fit *all* the data in Fig. 4 to a constant gave the statistically unacceptable result, $\varepsilon = 0.0084 \pm 0.0007$, $\chi^2 = 113$, confidence level 0.005. The dashed curve is the best fit of the data to an empirical expression of the form $\varepsilon = 0.03 - 0.006$ W. This result strongly suggests that a measurement of the energy dependence of the shape factor would be valuable to further explore the validity of the ξ-approximation.

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