Beta-Gamma Directional Correlation in the Decay of Eu^{152}†*

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The directional correlation between the 1459-kev beta group and the 345-kev gamma ray of Eu^{152} has been measured as a function of beta energy at energies above 800 kev. The experimental results show good agreement, at high energies, with the theoretical correlation for a first forbidden beta transition with $\Delta J=1$. The influence of the relative size of the matrix elements on the shape of the beta spectrum is discussed.

INTRODUCTION

THE decay scheme of Eu^{152} is shown in Fig. 1.[1] Previous work[2] indicates a unique shape for the 1459-kev beta group and a log*ft* product of 11.6. However, a spin of 3 has been measured[3] for the ground state of Eu^{152} indicating a spin change of only one for the 1459-kev beta group. In the present investigation measurements of the directional correlation between the 1459-kev beta group and the 345-kev gamma ray have been made.[4] In the theoretical development certain approximations as given by Morita and Morita[5] have been used. It is the purpose of this investigation to show the following: (a) The experimental results are inconsistent with the theory if the 1459-kev beta group is first forbidden unique. (b) The results are consistent with the theory, under the assumed approximations, if the beta decay is first forbidden with $\Delta J=1$. (c) The previous observation concerning the shape of the 1459-kev beta group[2] can be explained satisfactorily in view of the results of this experiment.

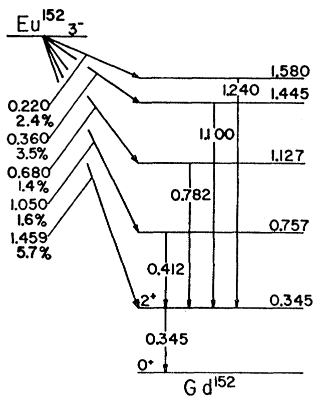

FIG. 1. Decay scheme of Eu^{152} ground state, electron emission branch, from reference 1.

EXPERIMENTAL PROCEDURE

The $Eu^{152-154}$ was produced at the Oak Ridge National Laboratory by irradiation of $Eu^{151-153}$ with thermal neutrons. Sources were prepared by evaporation of one or two drops of $EuCl_3$ in HCl solution on 0.2 mil aluminum foil. Three different sources were used. No change in intensity of the 345-kev gamma ray relative to the beta spectrum was noted for any of them over a period of six months.

The coincidence circuit was of the fast-slow type[6] and operated at a resolving time of about 10^{-7} second. The gamma detector used a $1\frac{1}{2}$-in. diameter by 1 in. high NaI(Tl) crystal. The beta detector used a $1\frac{1}{2}$-in. diameter by 0.28 in. high anthracene crystal which, along with the source, was mounted inside a thin wall aluminum vacuum chamber. The fast pulses to the coincidence circuit were taken from the amplifier discriminator outputs and the accidental coincidence rate was determined by inserting a 0.5-μsec delay in one of the outputs.

The angular correlation experiments were performed with the source 7.3 cm from the gamma detector and 7.6 cm from the beta detector. The gamma spectrum exhibited a strong peak at 345 kev and the gamma pulse-height analyzer was set on this peak throughout the experiment with a window width of approximately 20 kev. The beta pulse-height analyzer was calibrated with the 976-kev conversion electron of Bi^{207} and the 633-kev conversion electron of Cs^{137}. The beta analyzer window width was maintained at approximately 60 kev.

Measurements were made at angles of 90°, 135°, 180°, 225°, and 270° for beta energies of 900, 1100, and 1300 kev. Measurements were made at only 90°, 180°, and 270° for beta energies of 800, 1000, and 1200 kev.

The necessary correction for interfering gamma-gamma coincidences was determined by using a 0.5 cm Lucite absorber in front of the beta detector.

RESULTS

The differential angular correlation was examined in 100 kev increments of beta energy from 800 to 1300 kev. The results are listed in Table I. The indicated errors are probable errors due to statistical effects only. The A_i are the usual coefficients in the expansion of the correlation function in terms of even-order Legendre

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* This work based on a thesis to be submitted by Harry Dulaney, Jr., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
[1] *Nuclear Data Sheets*, National Academy of Sciences—National Research Council, NRC 58-1-55 (National Research Council, Washington, D. C.).
[2] J. M. Cork, M. K. Brice, R. G. Helmer, and D. E. Sarason, Phys. Rev. **107**, 1621 (1957).
[3] M. Abraham, R. Kedzie, and C. D. Jeffries, Phys. Rev. **108**, 58 (1957).
[4] H. Dulaney, Jr., L. D. Wyly, and C. H. Braden, Bull. Am. Phys. Soc. **4**, 391 (1959).
[5] M. Morita and R. S. Morita, Phys. Rev. **109**, 2048 (1958).
[6] F. K. McGowan, Phys. Rev. **79**, 404 (1950).

TABLE I. Experimental Results. The A_i are the coefficients in the expansion of the correlation function in terms of Legendre polynomials. R is the number of real beta-gamma coincidences at 180°. T/C is the ratio of total real coincidences to accidentals. $R/\gamma\gamma$ is the ratio of beta-gamma coincidences to gamma-gamma coincidences.

Beta energy (kev)	Uncorrected A_2	Uncorrected A_4	Corrected for geometry A_2	Corrected for geometry A_4	A_4 assumed 0 A_2	R	T/C	$R/\gamma\gamma$
800	−0.199		−0.217±0.013		−0.217±0.013	9600	2.35	7.8
900	−0.239	−0.016	−0.260±0.017	−0.021±0.030	−0.269±0.009	18 500	2.21	8.6
1000	−0.299		−0.324±0.012		−0.324±0.012	9500	1.76	10.6
1100	−0.310	+0.011	−0.337±0.021	+0.015±0.034	−0.330±0.012	10 000	1.48	16.3
1200	−0.320		−0.348±0.014		−0.348±0.014	7300	2.00	30.5
1300	−0.314	+0.007	−0.341±0.023	+0.009±0.040	−0.336±0.011	11 600	1.20	19.4

polynomials. The correction for the finite angular resolution of the detectors was made according to Rose.[7] No correction for the beta energy spread was made because of the relatively narrow beta channel and the slight variation of A_2 with W at energies greater than 1000 kev. Since there was no significant detection of a $P_4(\cos\theta)$ term at the energies where data were taken to determine it, the value of A_2 was calculated at each energy assuming $A_4=0$. The results at 800 and 900 kev lack significance because of interference from the 1050-kev beta group. An attempt has been made to correct A_2 at energies below 1050 kev for this interference. Assuming that the 1050-kev beta spectrum has the allowed shape and the 1459-kev beta group is 3.5 times as intense as the 1050-kev group,[2] the following percentage of the total beta-gamma coincidences are estimated to be due to the 1050-kev beta group: 12.5% at 800 kev, 6.5% at 900 kev, and 1.2% at 1000 kev. The values of A_2, assuming $A_4=0$, were then corrected under the assumption that the directional correlation involving the 1050-kev beta group is isotropic. This correction resulted in the following values for A_2: −0.246 at 800 kev, −0.288 at 900 kev, and −0.328 at 1000 kev. No correction (estimated <1%) was made at 800 kev for possible interference from the Compton gamma 833-kev beta group in the Eu^{154} decay.[2] Due to errors involved in this procedure, such as the estimate of the relative intensities of the two beta groups, the above must be regarded as an attempt to explain discrepancies between the experimental points and the theoretical curve rather than as a method of obtaining precise values.

DISCUSSION

The theory of beta-gamma angular correlation for first-forbidden beta decay as given by Morita and Morita[5] is used in this section. The notation, in general, follows their usage.

For the first forbidden, unique case ($\Delta J=2$, yes) with the spin sequence $4^-(\beta)2^+(\gamma)0^+$ the theoretical expression for A_2 is

$$A_2=+0.143\frac{p^2}{p^2+K^2},$$

[7] M. E. Rose, Phys. Rev. **91**, 610 (1953).

where p is the momentum of the electron expressed in mc units and K the energy of the neutrino expressed in mc^2 units. Here A_2 is positive for all beta energies and has a maximum value of +0.143 which occurs at the maximum beta energy. This is in obvious disagreement with the large negative A_2 obtained in the experiment and indicates that the ground-state spin of Eu^{152} is not 4^-.

For first forbidden beta decay with a $3^-(\beta)2^+(\gamma)0^+$ spin sequence the theoretical expression for A_2 is

$$A_2=\frac{(1/7)(6^{-\frac{1}{2}})b_{11}^{(2)}+(1/7)b_{12}^{(2)}+(2/7)^{\frac{1}{2}}b_{22}^{(2)}}{-(3^{-\frac{1}{2}})b_{11}^{(0)}+(5^{-\frac{1}{2}})b_{22}^{(0)}},$$

where the $b_{LL'}^{(n)}$ are paremeters defined by Morita and Morita[5] involving various combinations of the matrix elements for the beta interaction. If the following assumptions as given by Morita and Morita[5] are made: (1) $(\alpha Z)^2\ll 1$, (2) $V=\alpha Z/2\rho\gg W_0$, (3) The coupling constants (C_A, C_V, etc.) are real, (4) $C_A=C_A'$, $C_V=C_V'$, (5) $\mathfrak{M}(B_{ij})$ is large compared to the other matrix elements, and (6) VA interaction; then the $b_{LL'}^{(n)}$ may be simplified so that

$$A_2=\frac{-(p^2/7W)(Y+W/6)}{Y^2+\frac{1}{12}(K^2+p^2)}.$$

W is the total energy of the electron expressed in mc^2 units and $Y=\mu/\nu$, where

$$\mu=iVC_V\mathfrak{M}(\mathbf{r})-C_V\mathfrak{M}(\boldsymbol{\alpha})+VC_A\mathfrak{M}(\boldsymbol{\sigma}\times\mathbf{r}),$$
$$\nu=iC_A\mathfrak{M}(B_{ij}).$$

In Figs. 2 and 3, A_2 is plotted as a function of the beta kinetic energy for values of Y from 0 to 1.4. Curves for negative values of Y are not shown because they indicate A_2 coefficients that are of insufficient magnitude. The experimentally determined values of A_2, assuming $A_4=0$, from Table I are also shown on the figures with the vertical flags indicating the statistical error. A value of Y of either 1.1 or 0.13 gives an A_2 of approximately the correct magnitude at high energies but the variation with energy is more closely fitted with $Y=0.13$. The experimental points at 800 and 900 kev lack significance because of the previously discussed interference with the 1050-kev beta group.

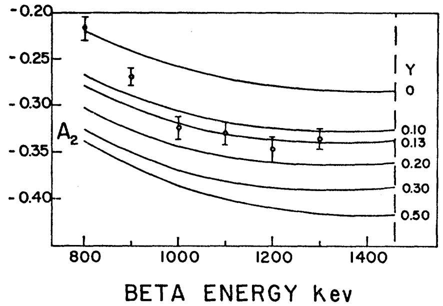

FIG. 2. Comparison of experimental data and theoretical curves for A_2 as a function of beta kinetic energy for values of Y from 0 to 0.5. Statistical errors are shown on experimental points.

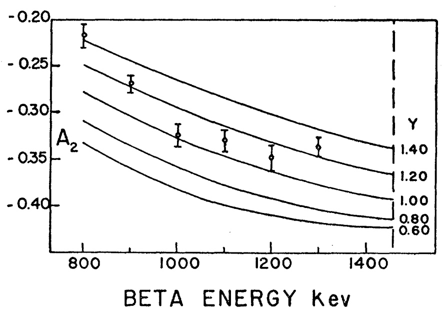

FIG. 3. Comparison of experimental data and theoretical curves for A_2 as a function of beta energy for values of Y from 0.6 to 1.4. Statistical errors are shown on experimental points.

The correction factor for the beta spectrum is of interest. If the same assumptions used in the analysis of the angular correlation data are made the theoretical shape factor, S, for first forbidden beta decay with $\Delta J=1$ is[5]

$$S=2|\mu|^2+\tfrac{1}{6}(K^2+p^2)|\nu|^2.$$

From the definition of μ and ν it can be seen that they are both energy independent. If all the matrix elements have roughly the same magnitude it would be expected that $|\mu|^2 \gg |\nu|^2$, unless an accidental cancellation of terms takes place in $|\mu|^2$. This is true because $|\mu|^2$ contains terms proportional to V and V^2 where $V \gg W_0$. Hence the shape factor would be essentially energy independent and the beta spectrum would have the allowed shape. However, under the assumption $\mathfrak{M}(B_{ij})$ large compared to the other matrix elements it is possible that $|\nu|^2 > |\mu|^2$ even if $V \gg W_0$. Specifically, if $Y=0.13$, then $\mu=0.13\nu$, and

$$S=[0.034+0.167(K^2+p^2)]|\nu|^2.$$

This shape factor is strongly energy dependent and, in fact, differs only slightly from the first forbidden unique shape factor. If $Y=1.1$ then $\mu=1.1\nu$ and

$$S=[2.42+0.167(K^2+p^2)]|\nu|^2.$$

This factor produces a shape which is between the first forbidden unique shape and the allowed shape. In Fig. 4, S is plotted as a function of beta energy from 800 kev to the end-point for values of Y from 0 to 1.1. The factors have been normalized to make them equal at 800 kev. Thus, under the assumed approximations, with a value of Y necessary to fit the angular correlation data, a theoretical shape factor for first forbidden beta decay with $\Delta J=1$ is obtained which is essentially the same as for the first forbidden unique case. This is in agreement with Cork's[2] observation of unique shape for the 1459-kev beta group.

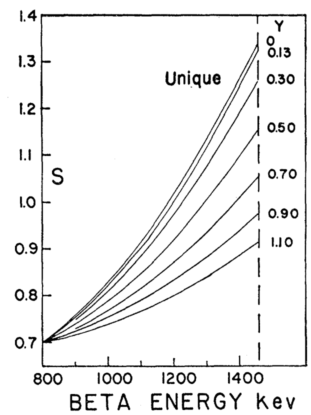

FIG. 4. Theoretical shape factor, S, for beta kinetic energy above 800 kev for values of Y from 0 to 1.1. The factors have been normalized to make them equal at 800 kev.

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Note added in proof. Langer, Smith, and Kline[8] have recently reported an experimental determination of the shape factor for the highest energy beta group of 13-year Eu^{152}. For energies above 1100 kev, their distribution is best fitted by a shape factor $K^2+0.791p^2+5\pm2$, with an endpoint of 1.483 ± 0.007 Mev. This result cannot be exactly fitted in terms of the parameter Y as given by Morita and Morita.[5] However in the high-energy region of the spectrum this result implies a value of $Y=0.7$ approximately. As noted above our experimentally determined angular correlation values are best fitted by an approximate value of Y of either 1.1 or 0.1. It appears that a value of $Y=1$ is most nearly compatible with both the experimental shape factor of Langer and out angular correlation results. Attention is called to the various approximations made by Morita and Morita[5] in order to describe the problem in terms of the parameter Y.

[8] L. M. Langer, W. G. Smith, and A. Klein, Bull. Am. Phys. Soc. 4, 426 (1959).