Beta-Gamma Directional Correlation in Eu^{154}

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The directional correlation between the nonunique first-forbidden outer beta group of end-point energy 1855 kev in Eu^{154} and the 123-kev cascade gamma ray in Gd^{154} has been measured at twelve beta-ray energies. The measured beta-gamma correlation coefficient ϵ ranges from $-(0.222\pm0.013)$ to $-(0.314\pm0.017)$ in the beta-energy interval 1150 to 1700 kev, after correcting for the attenuation due to the extranuclear field effect by measuring the attenuation factor $G_2=0.71\pm0.03$ in the 1277–123−kev gamma-gamma cascade in Gd^{154}. The correlation coefficient ϵ varies almost as (p^2/W) in this energy interval. The attenuation effect on the beta-gamma correlation coefficient under different physical conditions of the source has been demonstrated experimentally. An analysis of the data by an electronic computer leads to values of the matrix element ratios (Kotani's notation): $z=1$, $x=0.5\pm0.05$, $u=0\pm0.05$, and $Y=1.55\pm0.10$. It is concluded that the "modified B_{ij} approximation" is reasonably valid in this beta decay.

INTRODUCTION

THE theory of beta decay has been greatly simplified by the experimental evidence that V and A interactions are responsible for the process and $C_A=C_A'$ and $C_V=C_V'$. As a result, theoretical calculations have been greatly simplified for most of the experiments pertaining to beta decay.[1,2] Thus measurements of the various observables on the same beta decay, such as the shape correction factor, beta-gamma directional correlation, and beta-gamma circular-polarization correlation would yield quantitative determination of the relative contributions of the various nuclear matrix elements responsible for the decay. Of special interest are those cases in beta decay which show deviations from the ξ approximation.[2] Such deviations are expected in some decays from odd-odd to even-even nuclei which are characterized by abnormally large ft values; these beta decays have in general nonallowed shape and relatively large beta-gamma anisotropy. Such deviations are explained by Kotani[2] as arising from the "cancellation effect" or the "selection rule effect." The cases which show deviations of this kind offer valuable relations among the nuclear matrix elements.

The explicit expression for the beta-gamma directional correlation coefficient ϵ, as a function of energy of the beta-particle W (in units of m_0c^2) for a spin sequence $3^-(\beta)2^+(\gamma)0^+$ and where the ξ approximation breaks down, has been extracted from Kotani's general expressions[2] and is given here in a form suitable for numerical calculation.

$$\epsilon(p^2/W)^{-1}=N/D, \tag{1}$$

where

$$N=a_NY+b_N+c_Nx^2+d_Nx+e_Nu+f_NxY+g_Nux+h_Nu^2+j_NuY, \tag{2}$$

$$D=Y^2+b_D+c_Dx^2+f_DxY+h_Du^2+j_DuY, \tag{3}$$

and

$a_N=-\lambda_2/7,\quad b_N=-\lambda_1W/42,\quad c_N=(1/63)(W+2\lambda_2W_0),$
$d_N=(1/21)(\lambda_2W_0-W),\quad e_N=(1/21)(5W/2-\lambda_2W_0),$
$f_N=-2\lambda_2/21,\quad g_N=-d_N,\quad h_N=(1/9)(\lambda_2W_0/7-W/4),$
$j_N=\lambda_2/21,$
$b_D=(\lambda_1/12)(W^2-1)+(1/12)(W_0-W)^2,$
$c_D=(1/3)(W_0^2-1/3-4W_0W/3-2W_0/3W+4W^2/3),$
$f_D=(2/3)(1/W-W_0),\quad j_D=(2/3)(W_0-2W+1/W),$
$h_D=(1/3)(W_0^2/2-7/6-5W_0W/3+2W_0/3W+5W^2/3).$

In the above expressions the ratios of the matrix elements x, u, and Y are in Kotani's notation[2] ($z=1$); λ_1 and λ_2 contain Coulomb correction factors and are tabulated.[3] D in Eq. (3) is the shape correction factor $C(W)$.

Kotani[2] pointed out that special cases may exist among the nonunique first-forbidden transitions for which the B_{ij} matrix element dominates, either due to the cancellation effect or the selection rule effect; in the so-called "modified B_{ij} approximation," $u=x=0$ and one determines the only matrix element ratio Y responsible for the beta transition from the equation

$$Y=a_Np^2/2\epsilon W \pm[(a_N^2/4)(p^2/\epsilon W)^2-b_D+b_Np^2/\epsilon W]^{\frac{1}{2}}. \tag{4}$$

The shape-correction factor in this approximation becomes

$$C(W)=(1/12)(q^2+\lambda_1p^2)+Y^2. \tag{5}$$

The criterion for the validity of this approximation is that Y should be independent of W. Of the two values of Y given from Eq. (4) as obtained from the measurement of ϵ, one determines which one fits the experimental shape correction factor.

The present experiment aims at determining the beta-gamma directional correlation in Eu^{154} in the highest-energy beta group of 1855 kev ($W_0=4.63$) and the 123-kev $E2$ gamma ray corresponding to the spin

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sequence $3^-(\beta)2^+(\gamma)0^+$. The beta spectrum of this decay has a nonstatistical shape[4] given by the shape correction factor $C(W)=q^2+\lambda_1 p^2+20\pm5$. The log$ft$ value of this beta transition is 12.4 which is abnormally large compared to that of a normal nonunique first-forbidden transition. The half-life of the 123-kev state in Gd^{154} is measured[5] to be 1.2×10^{-9} sec. The 1277–123-kev gamma-gamma cascade has been shown recently to have large attenuation in both directional correlation[6] and in linear-polarization correlation[7] measurements. In fact, the extranuclear field effect of the magnetic hyperfine interaction type present in this gamma-gamma correlation has been utilized to determine the magnetic moment of the 123-kev state in Gd^{154}. The unperturbed correlation coefficient has also been found by a delayed-correlation experiment on this cascade.[6] In a solid polycrystalline source the directional correlation coefficient A_2 has been found in our experiment to be 0.161 ± 0.005. The unperturbed correlation coefficient as determined by Stiening and Deutsch[6] on this cascade is $A_2=0.227\pm0.006$, thus indicating an attenuation coefficient $G_2=0.71\pm0.03$ in our solid polycrystalline source. The beta-gamma correlation will be affected in the same way as in the gamma-gamma cascade. Thus we have here a means of correcting our beta-gamma directional correlation coefficient ϵ by knowing the attenuation coefficient G_2 present in the same source. Further, in the present experiment we have demonstrated with a liquid source prepared in a special way that the beta-gamma correlation is indeed dependent upon different source conditions.

During the course of this experiment a similar work was published by Sastry, Petry, and Wilkinson.[8] Without considering the attenuation in the measured correlation coefficient due to extranuclear field effect, they found from their data $x=-0.24\pm0.05$, $u=+0.05\pm0.03$, and $Y=0.76\pm0.08$, and concluded that the "modified B_{ij} approximation" does not strictly hold in this decay, unlike the case of the similar decay in Eu^{152}.[9–12] In the present work we shall show that the observed beta-gamma correlation coefficients, when properly corrected for the attenuation effects, yield results which can be reasonably fitted in the "modified B_{ij} approximation." The exact fitting of the corrected data was done with an electronic computer, to extract the matrix element ratios x, u, and Y.

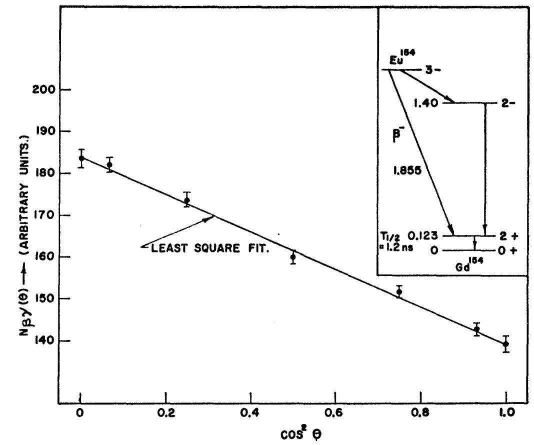

FIG. 1. Integral beta-gamma directional correlation in Eu^{154} with beta energy above 1350 kev. In the above plot the beta-gamma coincidences $N_{\beta\gamma}(\theta)$ have been plotted as a function of $\cos^2\theta$. The observed correlation coefficient is $\epsilon=-(0.178\pm0.007)$ which when corrected for geometry gives $\epsilon=-(0.196\pm0.007)$. The relevant portion of the decay scheme of Eu^{154} is shown at the inset.

EXPERIMENTAL PROCEDURE

The source used for the present work was produced by bombarding enriched Eu^{153} (95%) with thermal neutrons in the Oak Ridge National Laboratory Reactor in 1957. The source was deposited from a drop of $EuCl_3$ solution on a 0.6-mg/cm^2 Mylar foil over a diameter of about 3 mm. It was placed at the center of a vacuum chamber evacuated to less than 0.1 mm Hg. The vacuum chamber was 4 in. in diameter and made of $\frac{1}{32}$-in. thick aluminum coated inside with paraffin to reduce scattering.

The experimental setup was very similar to that used by Steffen.[13] The beta detector was a plastifluor cylinder with a conical well cut in it. This was optically coupled to an RCA 6342A photomultiplier. The source was at the apex of the conical well at a distance of 2 in. from the detector surface. The effective thickness of the detector was $\frac{1}{2}$ in. and the effective solid angle for beta-particle detection was 2.5% of 4π. Resolution for the K-conversion electron line of Cs^{137} was 19%. For beta-energy calibration, the following standards have been used: 490-kev $(K+L)$-conversion line in Bi^{207}, 624-kev K-conversion line in Cs^{137}, and 980-kev K-conversion line in Bi^{207}. Line shapes at these energies were also measured and used for resolution corrections. Gamma rays were detected by a $1\frac{3}{4}$-in. diam$\times\frac{3}{8}$-in. thick NaI (Tl) crystal mounted on a RCA 6342A photomultiplier. This crystal was placed at a distance of 3 in. from the source for the differential anisotropy measurements and 4 in. for the integral anisotropy measurements. The gamma counter was the movable counter situated outside the vacuum chamber and the gamma channel was adjusted to accept the 123-kev photopeak with a narrow window.

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The electronic system consisted of a "fast-slow" coincidence arrangement with a ten-channel analyzer for beta-energy selection. The gain of the beta channel was adjusted so that each channel-width of the analyzer corresponds to 50 kev. With this arrangement a 500-kev portion of the spectrum could be scanned at one single span. A resolving time of 2×10^{-8} sec was used for all the experiments. For coincidence counting, the multichannel analyzer was gated by the 123-kev gamma ray.

The integral beta-gamma correlation has been measured by an automatic angular correlation setup. Coincidences were recorded in the angular range 90° to 270° in steps of 15°. These measurements were made at beta energy above 1350 kev. The results are shown in Fig. 1.

The differential anisotropy $a=[W(180°)-W(90°)]/W(90°)$, where $W(180°)$ and $W(90°)$ are coincidence rates at 180° and 90°, was measured in the beta-energy region from 1150 kev to 1700 kev. Gamma-gamma coincidence background of the order of 25% at 1150 kev and gradually falling to zero at 1450 kev was found to be present. This was carefully measured by placing a 1.3-g/cm² plastic absorber which would stop all the beta rays in front of the beta crystal. Further. it was found that the amount of Eu^{152} present in the source contributes to the anisotropy in the lower energies (5% at 1150 kev, falling sharply to zero at 1300 kev). The contribution comes from coincidences between the 1480-kev beta group in Eu^{152} and the Compton part of the 344-kev gamma ray falling in the window at the 123-kev gamma-energy setting. This contribution was separately measured by measuring coincidences between the beta particles and the 344-kev photopeak in the same source and then calculating the amount caused by the Compton tail of the 344-kev gamma ray falling under the window setting corresponding to 123 kev.

Apart from the geometrical corrections, the following important corrections were applied to the experimentally observed anisotropies:

1. Resolution Correction

The correction for finite beta-energy resolution was carried out using the method due to Freedman *et al.*[14] from the experimentally observed line shapes. This correction is 4% at 1150 kev and increases to 10% at 1700-kev beta energy. The amount of correction appears to be large compared to what has been reported earlier[10] using a flat scintillator for detecting the beta particles. With a well-type scintillator, the back scattering of the electrons is negligible; the line shape of the 624-kev K-conversion line selected by coincidence with x rays and that of the 980-kev K-conversion line in Bi^{207} by coincidence with the 569-kev gamma ray have no appreciable back-scattering tails; on the contrary, using a flat scintillator for observing a monoenergetic line shape, one will always get a constant back-scattering tail up to zero energy, about 7% of the peak height.[14] In a beta spectrum observed with a well-type scintillator where back scattering is absent, there is a substantial contribution of low-energy electrons falling at higher-energy analyzer window settings due to the finite-resolution effect because of the steeply falling nature of a beta spectrum at the higher energies. This causes a reduction in the observed anisotropies at the higher energies, particularly in a case where the energy dependence of the anisotropy is large. On the contrary, using a flat scintillator, the back scattering of the higher energy electrons causes a pileup at the lower energy part of the beta spectrum, thereby apparently reducing the corrections due to resolution effects on the anisotropies. Measured values of the beta-gamma anisotropies in Eu^{152} with a well-type scintillator, when corrected in this way, have been found to agree very satisfactorily with the earlier magnetic spectrometer measurements of Fischbeck and Wilkinson[9] (see Table I). In Table III (column 4) the magnitude of the correction at various energies in Eu^{154} is shown.

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TABLE I. Comparison of the present measurements on the beta-gamma correlation coefficient in Eu^{152} with those of Fischbeck and Wilkinson.[a]

E (kev)	W (m_0c^2)	(Present measurements)	(Fischbeck and Wilkinson[a])
929	2.819		0.323±0.013
950	2.859	0.314±0.004	
974	2.906		0.315±0.006
1000	2.957	0.334±0.004	
1050	3.055	0.347±0.004	
1075	3.103		0.359±0.007
1100	3.153	0.362±0.004	
1125	3.202		0.360±0.004
1150	3.250	0.366±0.004	
1200	3.350	0.368±0.005	0.372±0.007
1250	3.446	0.380±0.005	
1277	3.500		0.374±0.006
1300	3.544	0.380±0.006	
1350	3.642	0.392±0.008	
1400	3.740	0.401±0.011	

[a] See reference 12.

2. Extranuclear Field Effect

The directional correlation coefficient is attenuated due to extranuclear field effect because of the finite lifetime of the 123-kev state in Gd^{154}. To measure this attenuation, the directional correlation of the 1277-kev and 123-kev cascade gamma rays was measured using a 2-in. diam×2-in.-thick NaI(Tl) crystal to detect the 1277-kev gamma ray. The solid polycrystalline source, which was employed for all the beta-gamma anisotropy measurements, was used. The observed directional correlation after geometrical corrections is given by $W(\theta)=1+(0.161\pm0.005)P_2(\cos\theta)+(0.002\pm0.006)P_4(\cos\theta)$. The unperturbed directional correlation coefficient A_2 as

TABLE II. Comparison of the attenuation in the beta-gamma directional correlation coefficient ϵ with beta energy above 1350 kev and in the 1277–123-kev gamma-gamma correlation coefficient A_2 under different physical conditions of the source.

	Solid source	Liquid source	Relative attenuation in the solid source compared to liquid source
Beta-gamma correlation coefficient ϵ	-0.196 ± 0.007	-0.211 ± 0.004	0.929 ± 0.037
Gamma-gamma directional correlation coefficient A_2	0.161 ± 0.005	0.187 ± 0.007	0.862 ± 0.040

determined by Stiening and Deutsch[5] from delayed-correlation measurements is 0.227 ± 0.006. Hence, the attenuation coefficient to be used for correcting the observed beta-gamma correlation coefficient ϵ is $G_2=0.71\pm0.03$.

In order to demonstrate whether the beta-gamma correlation is attenuated under different physical conditions of the source, a beta-gamma integral directional correlation measurement with a liquid source was undertaken. A drop of the same stock solution of $EuCl_3$ which was used to prepare the solid source was sandwiched between two Mylar foils 0.6-mg/cm^2 thick, thus forming a very well-defined circular film of thickness about 0.2 mm and of diameter about 5 mm. This source was put in the vacuum chamber with air introduced to avoid evaporation or rupture of the source. The experiment was performed under the same condition that was used to determine the beta-gamma correlation with the usual solid polycrystalline source. In either case the beta particle energy was selected above 1350 kev. The measured anisotropy as a function of angle is plotted in Fig. 2, where the results obtained with the solid polycrystalline source are also shown for comparison. The integral beta-gamma correlation with the solid source was observed in air also and was found to be unaffected in the energy region above 1350 kev. From Fig. 2, it is clearly demonstrated that the beta-gamma directional correlation in this cascade in Eu^{154} is affected by different physical conditions of the source, the anisotropy being

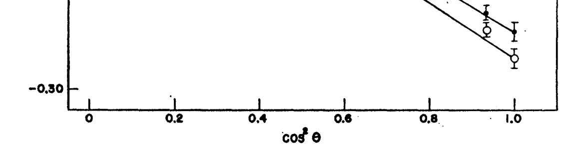

FIG. 2. Integral beta-gamma anisotropy in Eu^{154} with beta energy above 1350 kev with solid and liquid sources. The experimentally observed anisotropies in the two sources, without geometrical correction, are $a=-(0.245\pm0.010)$ in the solid source and $a=-(0.271+0.010)$ in the liquid source.

greater in the liquid state. To show that the beta-gamma correlation and gamma-gamma correlation are attenuated by the same amount, the 1277-kev–123-kev gamma-gamma directional correlation experiment with the same liquid source was also performed. The results are shown in Table II. It is obvious that within experimental errors, the attenuation is the same in both beta-gamma and gamma-gamma directional correlation measurements.

RESULTS

The integral correlation function in Eu^{154} with beta energy above 1350 kev, after the usual geometrical correction, can be expressed as

$$W(\theta)=1-(0.196\pm0.007)P_2(\cos\theta)+(0.004\pm0.008)P_4(\cos\theta).$$

The small value of the coefficient in the $P_4(\cos\theta)$ term indicates that the parity of Eu^{154} is odd.[2] The results are shown in Fig. 1 where the integral beta-gamma coincidences $N_{\beta\gamma}(\theta)$ are plotted against $\cos^2\theta$.

The differential beta-gamma angular correlation in Eu^{152} involving the 1483-kev beta group and the 344-kev cascade gamma ray was first measured to test the performance of the equipment. The results are shown in Table I. In the same table the magnetic spectrometer measurements of Fischbeck and Wilkinson[9] are also shown. The agreement between the two sets of value is quite satisfactory.

The beta-gamma correlation data in Eu^{154} are shown in Table III. Columns 4 and 7 show the effects of resolution correction and correction for attenuation due to extranuclear field, respectively. It is seen that ϵ ranges from -0.22 to -0.32 in an energy span 3.25 to 4.33 m_0c^2. To extract the matrix element ratios x, u, and Y from the observed energy dependence of ϵ, the following procedure was adopted: An exhaustive computation of $\epsilon(p^2/W)^{-1}$ as given in Eq. (1) for various values of x, u, and Y was undertaken with the aid of TIFRAC, the Institute's electronic computer, and the program was written in such a way that sets of values of u, x, and Y which give good fit with the experimental $\epsilon(p^2/W)^{-1}$ values were printed out. The range of values tried for x and u was from -0.9 to $+0.9$ in steps of 0.05, and the range for Y was from 0 to 3 in steps of 0.05. In this way a number of possible sets of x, u, and Y were found. A further choice was made on the basis of agreement with the experimentally observed shape

TABLE III. Summary of the Eu^{154} beta-gamma correlation data.

E (kev)	W (m_0c^2)	Observed anisotropy $-a$	Anisotropy corrected for resolution $-a$	$\epsilon=2a/(a+3)$	$-\epsilon$ corrected for geometry; $G_{\beta\gamma}=0.8812$	$-\epsilon$ corrected for attenuation effect; $G_2=0.71\pm0.03$
1150	3.250	0.183±0.010	0.195±0.010	−0.139±0.007	0.158±0.008	0.222±0.013
1200	3.348	0.178±0.009	0.190±0.009	−0.135±0.007	0.153±0.008	0.216±0.013
1250	3.446	0.196±0.007	0.210±0.007	−0.150±0.005	0.170±0.006	0.240±0.010
1300	3.544	0.207±0.007	0.223±0.007	−0.162±0.005	0.184±0.006	0.259±0.011
1350	3.642	0.220±0.004	0.234±0.004	−0.169±0.003	0.192±0.004	0.270±0.010
1400	3.740	0.238±0.004	0.252±0.004	−0.183±0.003	0.208±0.004	0.293±0.010
1450	3.838	0.241±0.004	0.258±0.004	−0.188±0.003	0.213±0.004	0.301±0.011
1500	3.935	0.247±0.005	0.265±0.005	−0.194±0.004	0.220±0.005	0.310±0.012
1550	4.033	0.242±0.006	0.261±0.006	−0.190±0.004	0.216±0.005	0.304±0.012
1600	4.131	0.245±0.008	0.265±0.008	−0.194±0.006	0.220±0.007	0.310±0.013
1650	4.229	0.254±0.009	0.275±0.009	−0.201±0.007	0.228±0.008	0.322±0.015
1700	4.327	0.244±0.012	0.267±0.012	−0.196±0.009	0.223±0.010	0.314±0.017

factor. The best fit has been found with the set $x=0.05$, $u=0$, and $Y=1.55$.

In Fig. 3, the experimental beta-gamma directional correlation coefficient ϵ has been plotted as a function of beta-particle energy W (in units of m_0c^2). The theoretical value of ϵ using Eq. (1) for $x=0.05, u=0$, $Y=1.55$ has also been shown.

In Fig. 4, the "reduced" correlation coefficient $\epsilon(p^2/W)^{-1}$ has been plotted as a function of energy. It is clearly seen that the value of $\epsilon(p^2/W)^{-1}$ is practically constant around the value -0.080 ± 0.008. It shows that ϵ varies almost as p^2/W over the energy region investigated in the present experiment. The theoretical value of $\epsilon(p^2/W)^{-1}$, using Kotani's expression given by Eqs. (1), (2), and (3) for the set $x=0.05$, $u=0$, $Y=1.55$, has also been plotted.

In Fig. 5, the shape correction factors calculated from the various sets around $x=0.05$, $u=0$, and $Y=1.55$ are compared with the experimentally observed shape factor of Langer and Smith.[4] They have been normalized with the mean experimental value of $C(W)$ at $W=3.94m_0c^2$. The set $x=0.05$, $u=0$, and $Y=1.55$ fits best both with the experimental values of ϵ and with $C(W)$. It is interesting to note that a set $x=0.7$, $u=0.5$, and $Y=2.55$ fits very well with the values of ϵ (not shown in Fig. 3) but is completely in disagreement with the observed shape correction factor. In this case the shape correction factor is found to decrease with energy wheres the shape factor experimentally observed increases with energy.

Lastly, in Fig. 6, the Y values, calculated from the experimentally observed correlation coefficients ϵ with the help of Eq. (4), which is true if the "modified B_{ij} approximation" is valid in this beta decay, are plotted as a function of beta-particle energy W. A value of $Y=1.45\pm0.10$ seems to give a good fit for most of the experimental points. The other value of Y as given by Eq. (4) has the value 0.08 ± 0.04. This value of Y cannot be responsible for this beta decay since, according to the Eq. (5), the spectral shape should be almost unique, which is contrary to observation.[4]

DISCUSSION

From the results of the present experiment on the energy dependence of the beta-gamma correlation coefficient ϵ and also from the observed experimental spectral shape $C(W)$, it can be concluded that the "modified B_{ij} approximation" is reasonably valid in the nonunique first-forbidden beta-decay of the 1855-kev beta group of Eu^{154}; the matrix element ratios respon-

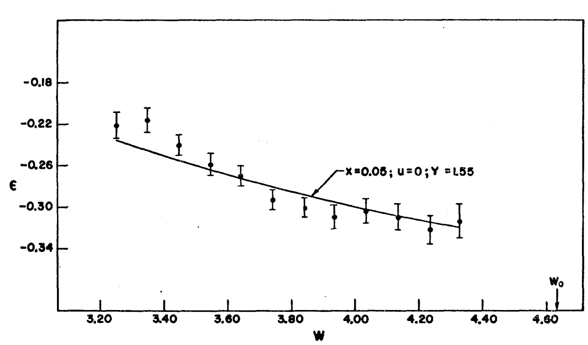

FIG. 3. The beta-gamma directional correlation coefficient ϵ plotted as a function of beta-particle energy W (in units of m_0c^2). The solid curve is a theoretical one with $x=0.05$, $u=0$, and $Y=1.55$.

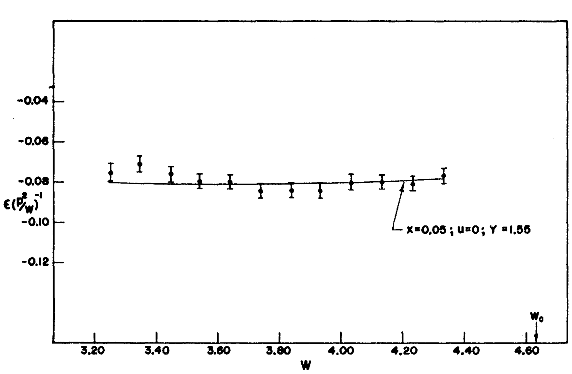

FIG. 4. The "reduced" correlation coefficient $\epsilon(p^2/W)^{-1}$ plotted as a function of the beta-energy W. The solid curve is Kotani's theoretical expression Eq. (1) with $x=0.05$, $u=0$, and $Y=1.55$.

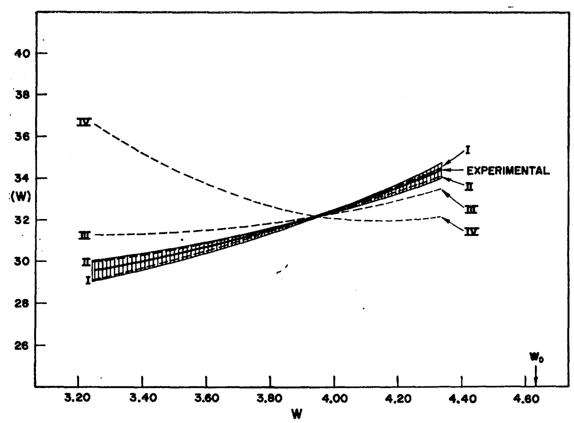

FIG. 5. Comparison of the theoretical shape correction factor $C(W)$ and the measured shape correction factor of Langer and Smith.[4] The theoretical shape correction factors are calculated using Kotani's complete expression Eq. (3) with the sets: I. $x=0$, $u=-0.05$, $Y=1.45$; II. $x=0.05$, $u=0$, $Y=1.55$; III. $x=0.1$, $u=0.1$, $Y=1.65$; IV. $x=0.7$, $u=0.5$, $Y=2.55$. Values of $C(W)$ for each set have been normalized with the mean experimental value at $W=3.94m_0c^2$. The shaded area denotes the error assigned to the experimental shape measurement.

sible for this decay are $z=1$, $x=0.05\pm0.05$, $u=0\pm0.05$, and $Y=1.55\pm0.10$. The corrected ft value, $f_ct=6.15\times10^{33}$ in natural units ($\hbar=m=c=1$), determines the standard matrix element $B_{ij}=1.6\times10^{-5}$. We have used $C_A=-1.21C_V$, $C_V=g=2.97\times10^{-12}$ (in natural units). The nuclear radius, $R=1.21\times10^{-13}A^{\frac{1}{3}}$ cm, in natural units becomes $R=1.67\times10^{-2}$ for Eu^{154}. Hence, the absolute values of the matrix element ratios can be computed in a form which is independent of any system of units and is given as follows:

$$\left|\int B_{ij}\right|/R=(0.98\pm0.10)\times10^{-3},$$

$$\left|\int \mathbf{r}\right|/R=(5.9\pm5.9)\times10^{-5},$$

$$\left|\int i\boldsymbol{\sigma}\times\mathbf{r}\right|/R=(0\pm4.9)\times10^{-5},$$

and

$$\left|\int i\boldsymbol{\alpha}\right|=(4.5\pm2.0)\times10^{-5}.$$

The above ratios clearly indicate the lack of overlap of the initial and final nuclear wave functions; for complete overlap, the values of $|\int B_{ij}|/R$, $|\int \mathbf{r}|/R$, and $|\int i\boldsymbol{\sigma}\times\mathbf{r}|/R$ would be of the order of unity, whereas $|\int i\boldsymbol{\alpha}|$ would be of the order of 0.1. Thus all the matrix elements involved in this beta decay are very much reduced; however, $|\int B_{ij}|/R$ is much less reduced compared to the other ratios, indicating some sort of selection rule effect operating in this decay. On the basis of the collective model, this particular beta decay in Eu^{154} is characterized by a change of K quantum number $\Delta K=3$, since the Eu^{154} ground state has $K=3$ and the 123-kev level in Gd^{154} is the first member of the ground-state rotational band having $K=0$. Thus this beta decay is highly K forbidden, which may very well account for the validity of the "modified B_{ij} approximation." An identical beta transition of 1483 kev in Eu^{152} has also the similar property in that the B_{ij} matrix element is predominant[9–12]; however, in this case the K-selection rule effect is untenable because the 344-kev level in Gd^{152} is a vibrational state of a spherical nucleus, and hence K is not a good quantum number.

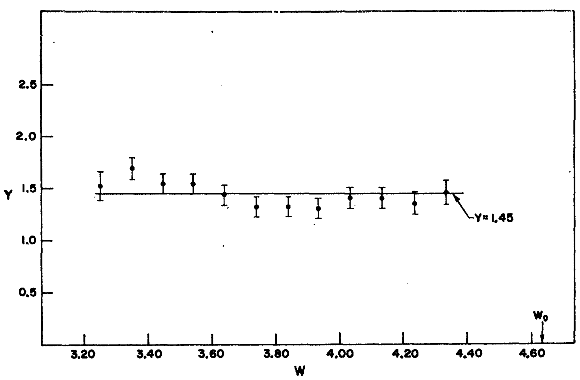

FIG. 6. Plot of Y versus beta energy W on the assumption of the "modified B_{ij} approximation."

The earlier work on the beta-gamma correlation in Eu^{154} by Sastry *et al.*[8] concludes that an appreciably large contribution is due to the matrix element ratio x. The values of the correlation coefficient ϵ reported by them are substantially less than that of ours by a factor 0.61. They have commented that if their measured values of ϵ are assumed to have suffered an attenuation of the order of 0.61, the "modified B_{ij} approximation" will be valid, which is consistent with the conclusion drawn from the present experiment. However, it may be pointed out that the attenuation factor G_2 due to extranuclear field effect, as measured by us in our solid polycrystalline source, is 0.71, which shows that the attenuation present in the sources used by Sastry *et al.*[8] was greater than that in ours.

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Note added in proof. During the course of publication of this work, another similar work has been published by Wyly *et al.*, Phys. Rev. **124**, 841 (1961) in which the attenuation effect on the beta-gamma correlation has not been taken into consideration. The results are similar to those of Sastry, Petry, and Wilkinson.[8]