Shape of Beta Spectra of Once Forbidden Transitions in the Decays of Ga^{72}, La^{140}, Eu^{152}, Eu^{154}, and Sb^{124}†

L. M. LANGER AND D. R. SMITH
Physics Department, Indiana University, Bloomington, Indiana
(Received April 4, 1960)

Magnetic spectrometer studies were made on the beta spectra of Ga^{72}, La^{140}, Eu^{152}, Eu^{154}, and Sb^{124}. The highest energy beta group of each of these transitions has an abnormally long comparative half-life and probably is a once forbidden decay from a 3− initial state to a 2+ final state. For all, the highest energy beta spectrum was found to have a nonstatistical, nonunique shape. On the assumption that the B_{ij} matrix element dominates the decay, the experimental shape factors were fitted empirically by $C=q^2+\lambda p^2+D$. The best fits were obtained for values of D equal to 15, 10, 5, 20, and 15 for Ga^{72}, La^{140}, Eu^{152}, Eu^{154}, and Sb^{124}, respectively.

INTRODUCTION

A MEASUREMENT of the detailed shape of the beta spectrum of a once forbidden transition can contribute information about the nuclear matrix elements. A sensitive analysis of a beta-ray spectrum can best be obtained from a study of a shape factor plot of the data. In this treatment of the data, the shape factor, $C\propto N/p^2F(W_0-W)^2$ is plotted against the energy W, where N is the number of beta particles per unit momentum interval, p is the momentum and W_0 is the maximum energy of the electron. F is a known function which describes the Coulomb effects on the electron as it leaves the nucleus. The theoretical shape factor for the spectrum of a once forbidden transition can, in general, be expressed by $C=k(1+aW+b/W+cW^2)$, where k, a, b, and c are parameters which are functions of nuclear matrix elements. For most nonunique once forbidden transitions, the beta spectrum has a shape which is indistinguishable from the statistical shape which is expected for the spectra of allowed transitions.

In such cases, one observes a constant shape factor since the energy dependence is masked by the dominance of the large constant term. Under certain circumstances, one may expect the effect of the constant term to be reduced and an energy dependent shape factor to become measurable. The suppression of the constant term may arise from cancellation among the nuclear matrix elements or from the action of additional selection rules such as those associated with **K** forbiddenness and **j** forbiddenness.[1] Nonstatistical, nonunique shapes have been observed[2-6] in the beta spectra of once forbidden transitions in the decays of RaE, Sb^{124}, Re^{186}, Ag^{111}, Rb^{86}, and Pr^{143}.

The existence of an abnormally long comparative half-life (high ft value) may be used as a guide toward identifying other once forbidden decays which might give rise to nonstatistical nonunique beta spectra. The same suppression of the matrix element which slows down the transition may also operate so as to make measurable an energy dependence in the shape factor.

In the present investigation, the highest energy beta-spectrum groups in the decays of Ga^{72}, La^{140}, Sb^{124}, Eu^{152}, and Eu^{154} have been studied in detail. These are the isotopes suggested by Kotani[1] as being of particular interest. They are probably all transitions from a 3− initial state to a 2+ final state and all are associated with abnormally high ft values.

The measurement of an experimental shape factor can, in general, be fitted quite readily by regarding the constants k, a, b, and c as completely arbitrary parameters. Ideally, one should like to have four independent equations in order to solve explicitly for these four parameters. In principal, one might obtain such information by combining the results of the spectrum shape measurement with the results deduced from beta-gamma angular correlation, beta-gamma polarization correlation and beta polarization studies. Under certain circumstances, theoretical considerations suggest that some of the parameters may be negligible and that others may be dominant.[1,7] In such cases, measurement of the beta-spectrum shape when combined with beta-gamma correlation measurements may yield definitive information about the nuclear matrix elements. If one assumes that the B_{ij} matrix element is dominant, then the theoretical shape factor can be conveniently written, in the notation used by Kotani, as

$$C=\tfrac{1}{12}(q^2+\lambda p^2)+k_n(1+a_nW+b/W+c_nW^2),$$

where k_n, a_n, b, and c_n are independent of energy to order $(\alpha z\rho)$ and $\lambda=\lambda_1$ is a known tabulated function.[8] For the case of a unique once forbidden transition ($\Delta I=2$, yes), $k_n=0$. The experimentally determined spectra of the isotopes studied in this investigation could be fitted empirically by a shape factor of the form

† This work was supported by the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] T. Kontani, Phys. Rev. **114**, 795 (1959).
[2] E. A. Plassman and L. M. Langer, Phys. Rev. **96**, 1593 (1954).
[3] L. M. Langer, N. H. Lazar, and R. J. D. Moffat, Phys. Rev. **91**, 338 (1953).
[4] F. T. Porter, M. S. Freedman, T. B. Novey, and F. Wagner, Phys. Rev. **103**, 921 and 942 (1956).
[5] R. L. Robinson and L. M. Langer, Phys. Rev. **112**, 481 (1958).
[6] J. H. Hamilton, L. M. Langer, R. L. Robinson, and W. G. Smith, Phys. Rev. **112**, 945 (1958).
[7] M. Morita and R. S. Morita, Phys. Rev. **109**, 2048 (1958).
[8] T. Kotani and M. Ross, Phys. Rev. **113**, 622 (1959).

$C \propto q^2+\lambda p^2+D$ where D is an adjustable constant. Such a fit is identical in form to that predicted for the modified B_{ij} approximation[1] for which $a_n=b=c_n=0$.

In some cases the measurement of a spectrum shape can be of help in the assignment of spins and parities to the initial and final nuclear states. Whereas a $\Delta I=2$, *yes* transition must give rise to a "unique" spectrum shape, the observation of such a $q^2+\lambda p^2$ shape is not forcing to such an assignment. On the other hand, the observation of a nonunique spectrum shape does preclude the possibility of a $\Delta I=2$ *yes* assignment.

EXPERIMENTAL PROCEDURE

In this investigation, the beta spectra were studied by means of the 40-cm radius of curvature magnetic spectrometer described earlier.[9–11] A proportional counter was used as a detector. For all of the high-energy spectrum measurements, the counter window was 0.9 mg/cm² aluminized Mylar. For measurements extending to lower energies in order to determine the total beta spectrum intensity, the counter window was an unsupported aluminized zapon film with a thickness of $\sim 150\ \mu g/cm^2$. Since rather intense sources were used in this investigation, additional checks were made in order to assure that low-energy electrons from the more intense inner groups were not being scattered so as to distort the measurements in the high-energy regions of interest. Even though the source strengths sometimes exceeded 20 mC, the background was never increased by more than 50% over that measured with the source removed.

The extreme criteria for the source thickness and backing, which were demanded for the investigation of possible small deviations in shapes of beta spectra,[10,11] were relaxed in these measurements, since the study of the spectrum shapes was limited to high-energy regions. Previous experience has indicated that the source thickness and backing used in these experiments should have no influence on the interpretation of the data. As a further check, a Sr^{90}-Y^{90} source was prepared with a thickness and backing comparable to that used in these measurements. Under these conditions the beta spectrum of Y^{90} was found to have the expected unique shape undistorted from 1.3 Mev to the end point at 2.3 Mev. For the present investigation, it was deemed advantageous to obtain the better statistical accuracy which is possible with stronger but somewhat thicker sources. Except in the immediate region of the end point, where the counting rates might be prohibitively low, an accumulation of 10 000 counts was made for each point of the spectrum.

In order to fit a shape factor to a beta spectrum, it is, of course, necessary to choose a value for W_0. For a nonstatistical F-K plot, the determination of W_0 involves the extrapolation of a curve rather than a straight line. If data with good statistical accuracy are obtained in the immediate neighborhood of the end point, the possible error in W_0 is not very large. Nevertheless, W_0 must be regarded as a slightly adjustable parameter. The F-K plot corrected by means of a shape factor which is based on a choice of W_0 must, in order to be self-consistent, be a straight line which extrapolates to the same value for W_0. Such a value for W_0 was determined for each run. The value of W_0 relative to the other values of W in a particular run involves less error than the determination of the absolute maximum energy release, E_0.

All the sources except the Sb^{124} were liquid deposited. The uniformity of the deposits was improved by the use of insulin.[12,13] Runs with sources of different thickness yielded identical spectra over the high-energy regions to which the spectrum shape studies were confined. The sources were 0.4–0.5 cm wide and the resolution of the spectrometer was 0.5–0.7%.

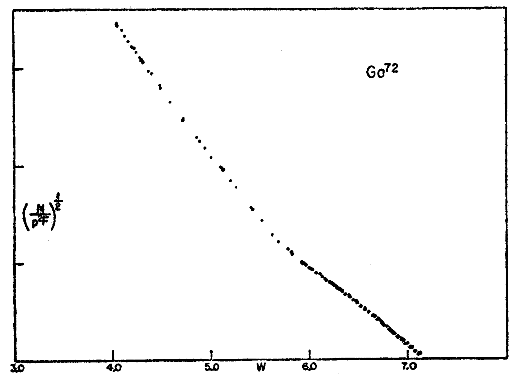

FIG. 1. Fermi-Kurie plot for the beta spectrum of Ga^{72}.

RESULTS

Gallium-72

The sources used in this experiment were prepared from several shipments from Oak Ridge. The sources were liquid deposited $GaCl_3$ on 0.25 aluminized Mylar which was covered with a $20\ \mu g/cm^2$ zapon film. The insulin technique for the uniform distribution of the source material does not work well directly on a Mylar surface. For measurements in the high-energy region the source thickness ranged from 0.5 mg/cm² to 2 mg/cm². All sources were covered with a $\sim 4\ \mu g/cm^2$ zapon film. Since the measurements made on the beta spectrum of the 3− to 2+ transition were restricted to a high-energy region, the thickness of the source did not have any distorting effect on the interpretation of the data. The decay was followed over a period of 57 hours and the half-life was found to be 14.2 hours with no evidence for any activity with a different half-life. Five

[9] L. M. Langer and C. S. Cook, Rev. Sci. Instr. **19**, 257 (1948).
[10] O. E. Johnson, R. G. Johnson, and L. M. Langer, Phys. Rev. **112**, 2004 (1958).
[11] J. H. Hamilton, L. M. Langer, and W. G. Smith, Phys. Rev. **112**, 2010 (1958).
[12] L. M. Langer, Rev. Sci. Instr. **20**, 216 (1949).
[13] V. J. Schaefer and D. Harker, J. Appl. Phys. **13**, 427 (1942).

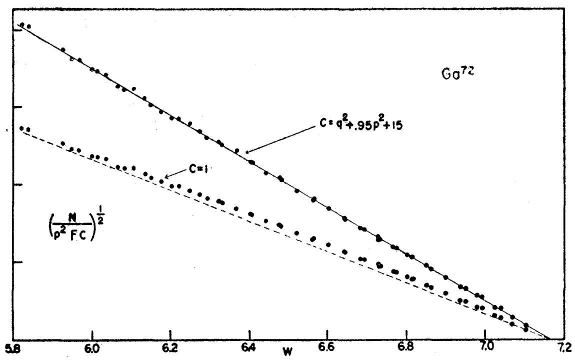

FIG. 2. F-K plot for the highest energy beta group in the decay of Ga^{72}. The dashed straight line is shown to emphasize the curvature in the ordinary statistical plot. The upper curve shows the linearization produced by application of the best value for the empirical shape factor.

runs were made on the spectrum, and they were corrected with this half-life.

A Fermi-Kurie (F-K) plot of the data above 1.5 Mev is shown in Fig. 1. Figure 2 shows a blown-up F-K plot of the highest energy beta group. It is seen that the ordinary plot for which $C=1$ does not lie on the dashed reference straight line. The upper plot shows how an empirical shape factor linearizes the F-K plot. A shape factor plot of the data using an extrapolated end point $W_0=7.165\ m_0c^2$ is shown in Fig. 3. This plot shows three attempts to fit the data. The best fit is obtained for $C=q^2+\lambda p^2+15\pm 10$. The maximum energy for this group is 3.15 ± 0.01 Mev. This value includes estimates of both statistical and instrumental error.

In order to obtain a measurement of the entire spectrum and of the inner groups a thinner source (~ 0.1 mg/cm^2) was used. The backing was a zapon and LC600 laminate $\sim 200\ \mu$g/cm^2 thick.

The F-K plot corrected with the shape factor $C=q^2+\lambda p^2+15$ was used in order to subtract the high-energy group from the total spectrum. The result of this subtraction yielded a spectrum for the next inner group. The extrapolated end point for this group occurs at $5.932\ m_0c^2$, a value which is consistent with the 0.63-Mev gamma-ray transition between the two final states. In spite of the large errors which are always introduced when making such subtractions, it was clear that the F-K plot for this group was different from a straight line. However, because of the large errors rather wide limits must be put on the shape factor fit. The experimental shape factor plot shown in Fig. 4 is indistinguisable within the accuracy of the measurements from an unique shape factor plot and is best fitted by the empirical relation $C=q^2+0.95p^2+0\pm 7$. Figure 5 shows the lineraization of the Fermi plot for this group after the application of the shape factor.

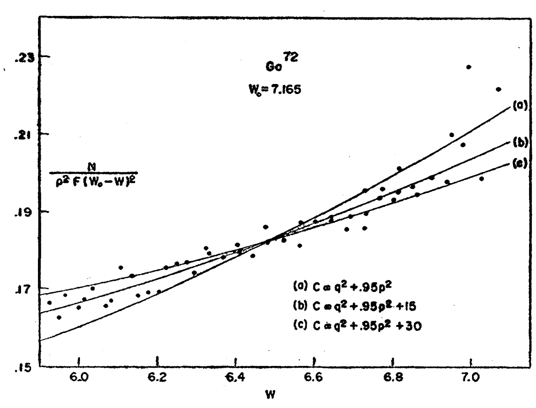

FIG. 3. Shape factor plot for the beta spectra of Ga^{72}.

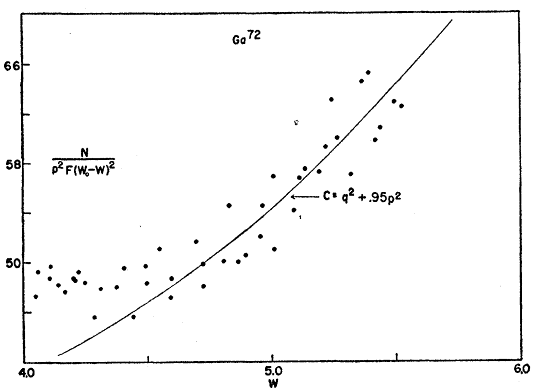

FIG. 4. Shape factor plot for the first inner group in Ga^{72}.

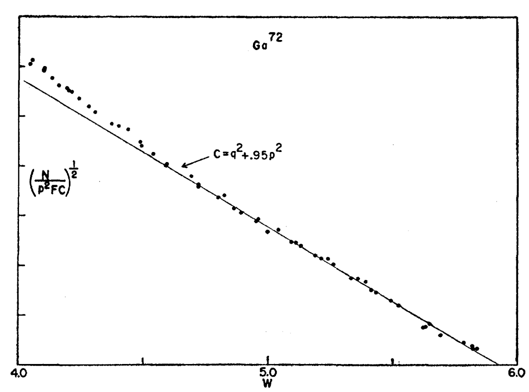

FIG. 5. F-K plot for the first inner group in the decay of Ga^{72}. The unique shape factor has been applied.

Further subtractions give evidence for two more groups whose Fermi plots could no longer be distinguished from straight lines. (Fig. 6) The extrapolated end points found for these groups were $4.84\ m_0c^2$ and $3.95\ m_0c^2$. The relative intensities, end-point energies and ft values for the four highest energy groups are shown in Table I. These values incorporate the effect of the nonstatistical shapes observed. Since the lower energy groups may be somewhat distorted because of source thickness effects, the ft values should be regarded as lower limits.

Lanthanum-140

Carrier-free $LaCl_3$ sources were prepared from several shipments from Oak Ridge. The sources were liquid deposited on thin laminated backings of zapon and LC600. The sources ranged in thickness from 1 mg/cm^2 to 2 mg/cm^2. A check of the decay of each source over a period of 6 half-lives indicated that there were no other activities with different half lives present.

Figure 7 shows a sample F-K plot of the high-energy portion of the spectrum. The ordinary statistical plot is curved and can be linearized by the application of the shape factor obtained from Fig. 8. The best fit to the data is obtained with a shape factor $C=q^2+0.845p^2+10\pm5$ using an extrapolated end point of $W_0=5.262$ m_0c^2. Considering statistical and possible instrumental errors, the best value for the end-point energy is $E_0=2.175\pm0.005$ Mev.

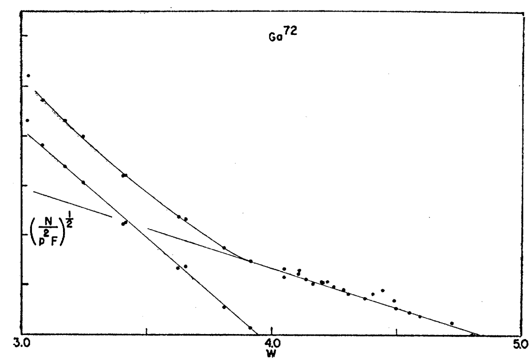

FIG. 6. F-K plot for lower energy inner groups in the decay of Ga^{72} obtained by successive subtraction.

TABLE I. End-point energies, relative intensities, and comparative half-lives for the highest energy groups in the beta decay of Ga^{72}.

E_0(Mev)	Int. (% of total)	logft
3.15	7.5	9.0
2.52	8.1	8.6
1.97	3.7	8.4
1.51	5.5	7.8

There has been some question in the past as to whether the highest energy transition was from 3− to 2+ or from 4− to 2+ levels. The shape factor fit indicates that the transition is not unique and therefore eliminates the 4− to 2+ possibility.[13a]

At this point, it is of interest to compare the shape factor plot of La^{140} with that obtained for Y^{90} under similar experimental conditions. The Y^{90} source was prepared to simulate that of La^{140} in thickness and backing. The measurements cover almost identical energy ranges. Figure 9 shows that the Y^{90} data cannot be fitted with anything much different from the "unique" $q^2+\lambda p^2$ shape factor. The plot of $q^2+\lambda p^2+5$ is shown to indicate the sensitivity of the fit.

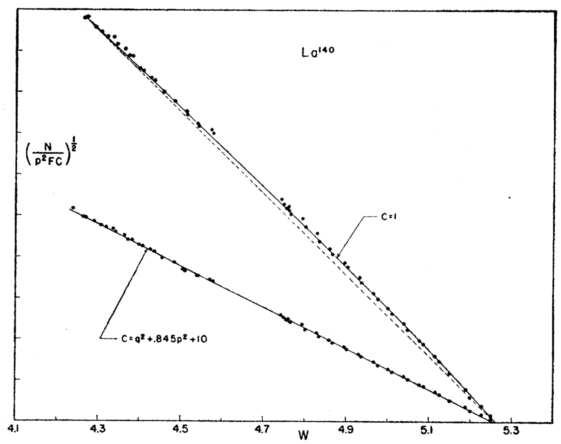

FIG. 7. F-K plot for the highest energy beta group in the decay of La^{140}. The dashed straight line is shown to emphasize the curvature in the statistical plot. The plot is linearized by the application of the best fitting shape factor.

Using the corrected F-K plot, the highest energy group of La^{140} was subtracted from the total spectrum. The next inner group was found to have an extrapolated end point of 4.295 m_0c^2 corresponding to $E_0=1.68\pm0.02$ Mev. This is consistent with the 0.487-Mev gamma ray reported in Ce^{140}. Because of the large errors introduced by the subtraction process, nothing definitive can be said about the shape factor of the inner group.

The highest energy group was found to be 5.7% of the total, leading to an ft value of 9.5. Because of possible low-energy distortion of the total spectrum, this value should be regarded as a lower limit.

The gap in the data shown in Figs. 7 and 8 is the energy region in which internal conversion lines were observed corresponding to an interesting $0+\rightarrow0+$ radiationless transition in Ce^{140}. We find for the energy of this transition 1.910 ± 1.004 Mev. On the same run, the internal conversion electrons corresponding to the transition from the first excited state in Ce^{140} to the ground state were also measured. On the basis of the same calibration, we find 1.596 ± 0.006 Mev for that transition. For the 1.910-Mev transition, we find a $K/(L+M)$ ratio of 5.14. For the 1.596-Mev transition the $K/(L+M)$ ratio is found to be 6.62.

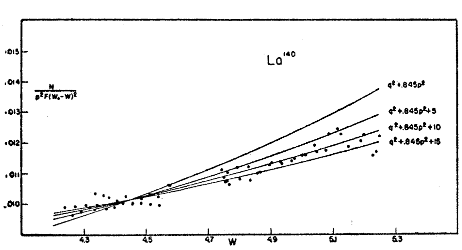

FIG. 8. Shape factor plot for the highest energy beta group in the decay of La^{140}.

[13a] *Note added in proof.*—The spin of La^{140} has been determined to be $I=3$ by the atomic beam magnetic resonance method by F. R. Petersen and H. A. Shugart, Bull. Am. Phys. Soc. II, 5, 343 (1960).

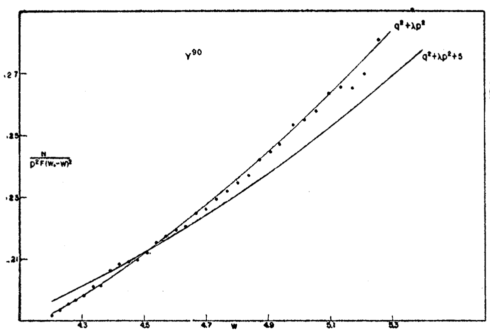

FIG. 9. Shape factor plot for the high-energy portion of the unique spectrum in the decay of Y^{90}.

The gamma-ray spectrum was examined with a NaI scintillation counter and 100-channel analyzer in a search for any gamma radiation associated with the 1.9-Mev transition. The absolute intensity of the 2.5-Mev gamma ray has been measured[14] as 0.05 quanta/disintegration. By comparison with the intensity of the 1.6-Mev and 2.5-Mev gamma-ray intensities, an upper limit of less than 5×10^{-4} quanta/disintegration may be set for any 1.9-Mev radiation. This leads to an internal conversion coefficient of greater than 2 for the 1.9-Mev transition. Clearly, this value is too high for anything but a 0+ to 0+ radiationless transition. Dzhelepow *et al.*[15] have also identified this as an electric monopole transition.

Europium-152

The sources of this activity were prepared from EuO_3, enriched to 91.9% in Eu^{151}, which was irradiated in the Brookhaven reactor for 70 days with a neutron flux of $\sim1.6\times10^{13}n/cm^2$ sec. The sources were liquid deposited on 0.25-mil aluminum coated Mylar covered by a thin zapon film. The source thicknesses were from 0.03 mg/cm^2 to 1.5 mg/cm^2. All sources were covered by a thin zapon film to reduce the danger of contaminating the spectrometer.

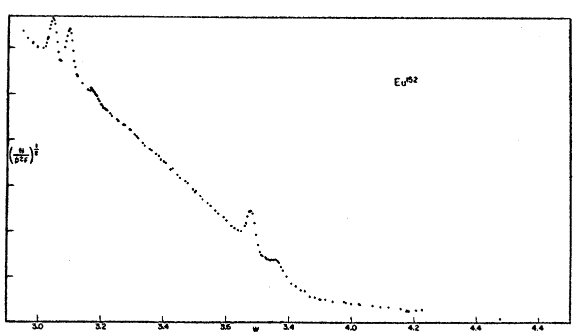

FIG. 10. F-K plot for the high-energy portion of the beta spectrum of Eu^{152} before subtraction of the Eu^{154} contaminant.

[14] V. A. Arkhipov, Atomnaya Energ **3**, 335 (1957) translation: Soviet J. Atomic Energy **3**, 1163 (1957).
[15] B. S. Dzelepow, Yu. V. Kholnov, and V. P. Prikhodtseva, Nuclear Phys. **9**, 665 (1959).

Several weeks elapsed between the time when the material was removed from the reactor and the beginning of the first experimental run. Data on subsequent runs were all consistent within counting statistics. No evidence for any short half-life contaminants was found in the spectrometer data or in gross decay curves checked against a uranium standard.

Previous measurements on the shape of the highest energy beta spectrum of Eu^{152} have suggested that the shape was "unique"[16,17] or that the shape was indistinguishable from the statistical shape[18] as evidenced by a straight line F-K plot. Since there are internal conversion lines occupying part of the energy interval available for spectrum shape study, the better resolution employed in the present investigation offered the possibility of obtaining a more definitive answer.

Figure 10 shows a typical F-K plot of the data in the

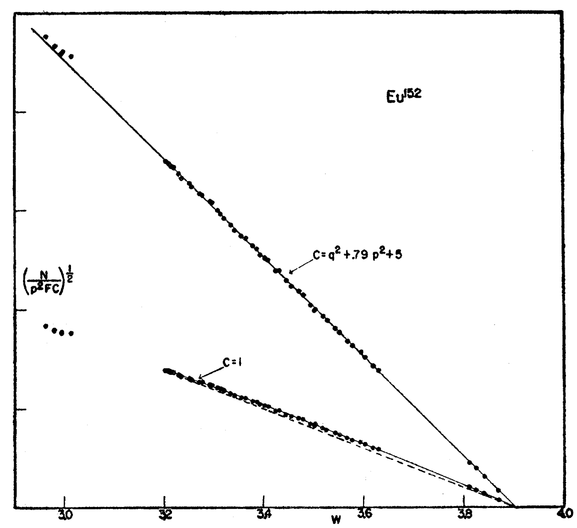

FIG. 11. F-K plot for the high-energy beta spectrum in the decay of Eu^{152}. The dashed straight line is shown to emphasize the curvature in the statistical plot. The upper curve shows the linearization of the data after application of the best fitting shape factor.

high-energy region above the end point of the next inner group. The tail of the distribution arises from the weak Eu^{154} impurity. Although the Eu^{154} spectrum is found to have a nonunique, nonstatistical shape, the intensity present in the Eu^{152} sample was so weak that the subtraction of this tail was insensitive to the shape factor assumed for it.

Figure 11 shows the F-K plot for Eu^{152} after subtraction of the weak Eu^{154} contribution. The lower data represent the ordinary F-K plot with a constant statistical shape factor. The dashed straight line is presented to emphasize the curvature. The upper data show the

[16] J. M. Cork, M. K. Brice, R. G. Helmer, and D. E. Sarason, Phys. Rev. **107**, 1621 (1957).
[17] S. K. Bhattacherjee, T. D. Nainan, S. Raman, and B. Sahai, Nuovo cimento **7**, 501 (1958).
[18] D. E. Alburger, S. Ofer, and M. Goldhaber, Phys. Rev. **112**, 1998 (1957).

linearization after the application of the best fit shape factor. The extrapolated end point is $W_0=3.902\ m_0c^2$ corresponding to $E_0=1.483\pm0.007$ Mev.

A shape factor plot of Eu^{152} data is shown in Fig. 12. The best empirical fit is obtained with $C=q^2+\lambda p^2+5\pm2$.

The intensity of the highest energy beta group was found to be 17.6% of the total negative beta spectrum.

The high-energy internal conversion lines were examined closely and correspond to a transition energy of 1.412 ± 0.006 in Sm^{152}. The $K/(L+M)$ ratio was measured to be 4.88.

Europium-154

For this study, EuO_3 enriched to 95% in Eu^{153} was irradiated in the Brookhaven reactor for 1195 hours with a neutron flux of $\sim1.6\times10^{13} n/\text{cm}^2$ sec.

The source was liquid deposited on a 0.25-mil aluminized Mylar film surfaced with a film of zapon. The source thickness was ~1 mg/cm². Since the measurements were restricted to the high-energy region, the source thickness and backing had no measurable effect on the beta spectrum.

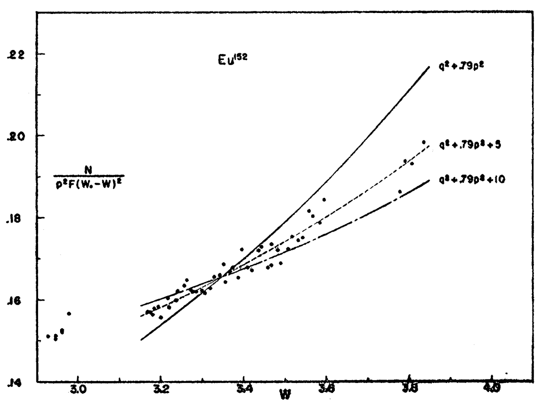

FIG. 12. Shape factor plot for the highest energy group in the decay of Eu^{152}.

Initial measurements indicated the presence of a considerable intensity of 15-day Eu^{156} activity. After four months, the Eu^{156} activity was reduced to a negligible value and the study of the Eu^{154} spectrum was begun. The presence of Eu^{155} activity does not contribute in the high-energy region to which the spectrum shape measurements were confined. The data obtained on six runs were all found to agree and no indication of any other short period activity was detected. Since there was some Eu^{152} present in the source, the measurements on the Eu^{154} spectrum were limited to energies above 1.483 Mev.

Figure 13 is an F-K plot of the high-energy beta spectrum of Eu^{154}. The data do not fall on a statistical straight line. The extrapolated end point is $W_0=4.630\ m_0c^2$ corresponding to $E_0=1.855\pm0.005$ Mev. Figure 14 is a shape factor plot of the data. The best fit is obtained

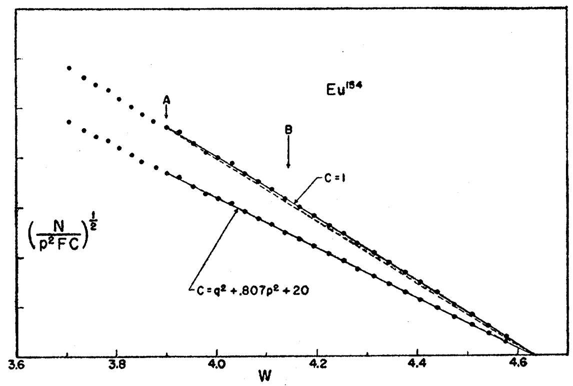

FIG. 13. F-K plot for the high-energy beta spectrum in the decay of Eu^{154}. Arrow "A" indicates the end-point energy for the Eu^{152} contaminant. Arrow "B" indicates the end-point energy for a hypothetical first inner group with $E_0=1.6$ Mev. The dashed straight line is shown to emphasize the curvature in the statistical plot of the data. The lower plot shows the linearization of the data after the application of the best fitting shape factor.

with $C=q^2+\lambda p^2+20\pm5$. The application of this shape factor linearized the F-K plot as shown in Fig. 13.

The proposed[19] decay scheme of Eu^{154} suggests that the first inner beta group should have an end point at 1.6 Mev and an intensity of about $\frac{1}{3}$ that of the 1.855-Mev beta transition. Both the F-K plot and the more sensitive shape factor plot give no indication of any 1.6-Mev transition with an intensity of that order of magnitude. Within the statistics of our measurements, the highest energy spectrum of Eu^{154} shows no indication of a second group down to 1.48 Mev, at which energy the contribution from the Eu^{152} contaminant becomes evident. The arrows at A and B in Figs. 13 and 14 mark the end-point energies for the spectrum of Eu^{152} and for the postulated 1.6-Mev group in Eu^{154}. All the shape factor fits are normalized to the experimental intensity at an energy above 1.6 Mev.

Antimony-124

Since the decay of the highest energy group in Sb^{124} falls in the same class of $3-$ to $2+$ once forbidden transitions with abnormally long comparative half-lives, the data

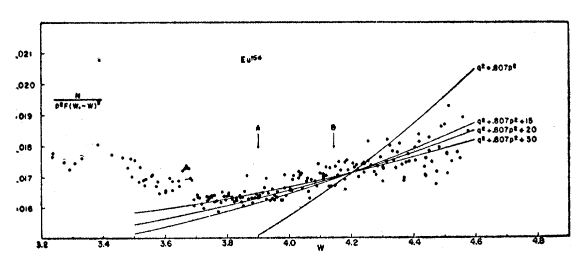

FIG. 14. Shape factor plot for the high-energy beta spectrum of Eu^{154}. The arrow "A" indicates the end-point energy for the Eu^{152} contaminant. The arrow "B" indicates the end-point energy for the hypothetical 1.6-Mev inner group.

[19] *Nuclear Data Sheets*, National Academy of Sciences, National Research Council (U.S. Government Printing Office, Washington, D. C.).

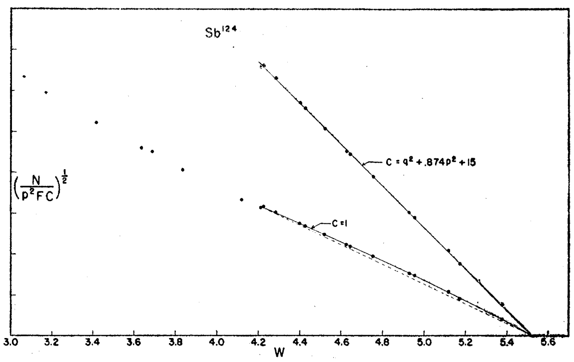

FIG. 15. F-K plot for the highest energy beta spectrum in the decay of Sb^{124}. The dashed straight line is shown to emphasize the curvature of the statistical plot. The upper curve shows the linearization of the data after application of the best-fitting shape factor.

obtained earlier[3] were reanalyzed in a similar manner suggesting the dominance of the B_{ij} matrix element. In the earlier work, it was assumed for the shape factor fit that the contribution from the B_{ij} matrix element was negligibly small.

The F-K plot of the high-energy portion of the Sb^{124} beta spectrum is shown in Fig. 15. A shape factor plot of the data is shown in Fig. 16. On the assumption that the B_{ij} matrix element dominates, empirical shape factors of the form $C=q^2+\lambda p^2+D$ were fitted to the data. A best fit is obtained with $D=15\pm5$. The upper plot in Fig. 15 shows the linearization of the F-K plot when this shape factor is applied.[19a]

DISCUSSION

The highest energy beta spectra in the decays of Ga^{72}, La^{140}, Eu^{152}, Eu^{154}, and Sb^{124} all exhibit shapes which are nonstatistical and nonunique. These transitions are all from a $3-$ initial state to a $2+$ first excited state in the daughter isotope. All have abnormally high *ft* values.

It was possible to fit the beta spectrum of each of these transitions with an empirical shape factor of the form $C=q^2+\lambda p^2+D$. The choice of this form for the shape factor was dictated by the suggestion by Kotani that all the above decays may be dominated by the B_{ij} matrix element. For such cases, Kotani suggested writing the theoretical shape factor in the convenient form

$$C=\tfrac{1}{12}(q^2+\lambda p^2)+k_n(1+a_nW+b/W+c_nW^2).$$

For the so-called "modified B_{ij} approximation,"

$$a_n=b=c_n=0 \text{ and } k_n=Y^2.$$

$$Y=\frac{-C_v}{C_a}\frac{\int i\alpha}{\int B_{ij}}-\frac{\alpha Z}{2\rho}(u+x),$$

where the notation is the same as Kotani's.

If, from a measurement of the beta-gamma angular correlation as a function of beta-ray energy, one determines that the modified B_{ij} approximation is valid, then the empirical value of D used to fit the spectrum shape is approximately equal to $12Y^2$. The beta-gamma angular correlation measurement yields two possible values for Y. By knowing D, it is possible to determine which of the two values of Y is more likely to be correct.

An example occurs in the case of Eu^{152}. Wilkinson and Fischbeck,[20] measuring the beta-gamma angular correlation as a function of beta-ray energy, found the modified B_{ij} approximation is valid, and obtain $Y=0.69\pm0.06$ or 0.23 ± 0.06. The value of D obtained from the spectrum shape suggests that the higher value of Y is appropriate. Similar measurements on the β-γ angular correlation by Sunier, Debrunner, and Scherrer[21] report a value for $Y=0.68\pm0.12$. The beta-gamma correlations for Eu^{152} reported by others[22,23] do not show such good agreement.

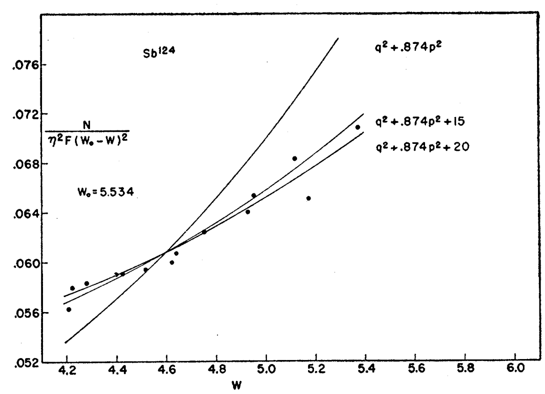

FIG. 16. Shape factor plot for the highest energy beta spectrum in the decay of Sb^{124}.

ACKNOWLEDGMENTS

The authors are grateful to Dr. D. Alburger for his cooperation in obtaining the europium irradiations. Mr. D. Camp, Mr. D. Howe, and Mr. M. Klein helped with some of the measurements. Professor M. Ross and Professor T. Kotani were very helpful with discussions of theoretical aspects of the problem.

[19a] *Note added in proof.*—The Sb^{124} spectrum was remeasured with a much stronger source which yielded somewhat better statistical data. The new data are best fitted with a value of $D=7\pm4$. This lower value for D reduces, but does not eliminate, an apparent discrepancy between our results and the conclusions of R. M. Steffen, Phys. Rev. Letters 4, 290 (1960) and of G. Hartwig and H. Schoppev, Phys. Rev. Letters 4, 293 (1960).

[20] H. J. Fischbeck and R. G. Wilkinson (to be published).

[21] J. W. Sunier, P. Debrunner, and P. Scherrer, Nuclear Phys. (to be published).

[22] S. K. Bhattacherjee and S. K. Mitra, Nuovo cimento (to be published).

[23] H. Dulaney, L. D. Wyly, and C. H. Braden, Bull. Am. Phys. Soc. 4, 391 (1959).