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Small Deviations Observed in Beta Spectra: In^{114}, Y^{90}, and P^{32}†

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The beta spectra of In^{114}, Y^{90}, and P^{32} (all of which decay by pure Gamow-Teller radiations) have been very carefully studied in a magnetic spectrometer. The Fermi-Kurie plots of all three spectra exhibit small deviations from linearity corresponding to an excess of low-energy electrons. All of the evidence indicates that the observed nonstatistical shapes represent the true spectra and are not the result of instrumental distortions. The Fermi-Kurie plots of these three isotopes can be linearized by a $(1+b/W)$ correction factor (in addition to the once-forbidden, unique shape factor in the case of Y^{90}).

INTRODUCTION

INCIDENTAL to their investigation of the RaE spectrum, Plassmann and Langer also measured the supposedly well-known spectrum of Y^{90} to check on the performance of the equipment.[1] After correcting the data with the unique once-forbidden shape factor, the Y^{90} spectrum still exhibited a small excess of low-energy particles. This effect was small but appeared to be outside the limits of experimental error. Preliminary studies at the time suggested that the deviation was not instrumental in origin.

The observed Y^{90} spectrum instigated a long and detailed investigation to determine whether the observed deviation was indeed real. Because of the small magnitude of the effect, caution had to be exerted in the interpretation of the data. Careful studies of the spectra of Y^{90}, In^{114}, and P^{32} were made under various experimental conditions.[2] These three isotopes decay by pure Gamow-Teller radiations but differ in their type of forbiddenness. In^{114} is an allowed transition $\Delta I=1$, *no*; Y^{90} is a unique, once-forbidden transition $\Delta I=2$, *yes*; P^{32} is an allowed, presubably l-forbidden, transition $\Delta I=1$, *no*.[3-5] Similar deviations were found in the spectra of all three isotopes.

Originally, before the advent of parity nonconservation, the low-energy deviations were of interest because they seemed to indicate the presence of Fierz-type interference[6] between T and A for the pure Gamow-Teller transitions. Since this conclusion was in disagreement with other evidence that Fierz interference was much smaller than determined from the measurements of beta spectra,[7] much effort was expended to determine whether these deviations from the statistical shape were real or instrumental. A more definitive check on the interpretation of the observed deviations as Fierz interference would be to observe whether the effects are also present in positron emitters. The shape factor for Fierz interference is of the form $(1+b/W)$, where the sign of the constant b would be expected to to be different for positrons and electrons. A careful investigation of a positron spectrum was eventually made with Na^{22}. The results of that investigation and a general discussion of the whole problem are presented in the following paper.[8]

EXPERIMENTAL APPARATUS

The Spectrometer

In this investigation, a high-resolution, 40-cm radius of curvature, 180-degree focusing, shaped magnetic field spectrometer[9] was used. The magnet current is stablized to better than 0.01% by means of an electronically regulated constant-current supply.[10] The magnetic field was measured to an accuracy of 0.1% with a null detection method described elsewhere.[11] A magnet cycling procedure was followed such that the proper field shape was obtained independent of field strength. The spectrometer chamber was maintained at a pressure lower than 5×10^{-6} mm of Hg. The spectrometer was calibrated by means of the K internal conversion line arising from the 661-kev[12] gamma-ray transition of Ba^{137}.

The large size of this spectrometer and the baffle system minimize scattering of electrons into the detector. The scattering of electrons might be expected to result in trajectories which would cause an electron to be counted in a momentum interval either higher or lower

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[1] E. A. Plassmann and L. M. Langer, Phys. Rev. **96**, 1593 (1954); E. A. Plassmann, Ph.D. thesis, Indiana University, September, 1954 (unpublished).

[2] O. E. Johnson, Ph.D. thesis, Indiana University, January, 1956 (unpublished); also see L. M. Langer, *Proceedings of the Rehovoth Conference on Nuclear Structure* (North-Holland Publishing Company, Amsterdam, 1958), p. 437.

[3] Pohm, Waddell, and Jensen, Phys. Rev. **101**, 1315 (1956). This article gives extensive references to earlier work on P^{32} and Y^{90}.

[4] Mayer, Moszkowski, and Nordheim, Revs. Modern Phys. **23**, 315 (1951).

[5] L. W. Nordheim, Revs. Modern Phys. **23**, 322 (151).

[6] M. Fierz, Z. Physik **104**, 553 (1937).

[7] R. Sherr and R. H. Miller, Phys. Rev. **93**, 1076 (1954).

[8] Hamilton, Langer, and Smith, following paper [Phys. Rev. **112**, 2010 (1958)].

[9] L. M. Langer and C. S. Cook, Rev. Sci. Instr. **19**, 257 (1948).

[10] W. C. Elmore and M. Sands, *Electronics—Experimental Techniques* (McGraw-Hill Book Company, Inc., New York, 1949), p. 390.

[11] L. M. Langer and R. F. Scott, Rev. Sci. Instr. **21**, 522 (1950).

[12] L. M. Langer and R. D. Moffat, Phys. Rev. **78**, 74 (1950).

than that of its true momentum. The possible scattering of low-momentum electrons into higher-momentum regions was investigated by studying the shape of internal conversion lines for various baffle settings. It was found that the shape of the lines was independent of baffle position. The "high-momentum edge" of the line remained almost perpendicular to the momentum axis whereas scattering of this type would cause this edge to be less sharply defined. The absence of counts above normal background beyond the end point of various beta spectra constitutes further evidence against this type of scattering. Evidence against the scattering of high-momentum electrons into lower-momentum regions is based on the fact that the cutoff of counter windows occurs very sharply at the energy predicted by theory. It is believed that the scattering of electrons into the detector in this spectrometer is completely negligible.

The Detector

The determination of the "true shape" of a beta spectrum requires that the detection of beta particles be of constant if not 100% efficiency. The variation of detection efficiency because of count rate losses for the source intensities used in these investigations is completely negligible.

The Geiger-Müller counter was a stainless steel end-window counter with a loop anode.[1] The counter gas consisted of a carefully dried mixture of one part ethylene and nine parts argon. The gas flowed through the counter at a uniform rate at a pressure of 9.8 cm of Hg, maintained constant to 1.5% by a Cartesian manostat.[13] The operating characteristics of counters of this particular design were studied to determine the optimum pressure with regard to constancy of efficiency, plateau length and slope, and pulse quality. Investigation showed conclusively that the regulation of pressure to 1.5% at 9.8 cm of Hg and the regulation of counter voltage to better that 1% were more that adequate for the stable performance and constant efficiency of the counter. Comparison runs carried out with a side-window counter, a beaded-anode end-window counter, and, later, with a proportional counter[8] indicated that there was no inherent energy sensitivity in the operation of this detector.

A typical counter had a threshold at about 950 volts at a pressure of 9.8 cm of Hg and a plateau over 200 volts long with a slope of 0.6% per 100 volts. The counter windows were 0.25-mil Mylar with a 100-μg/cm^2 aluminum coating on one side. The surface density of these windows was 910 μg/cm^2. This window thickness corresponds to the range for 22-kev beta particles.[14] These windows should not distort the beta spectrum above 110 kev.

Measurement Procedures

Since comparisons were to be made among several measurements of spectra obtained from a single source and among measurements made on various sources of each isotope, definite experimental procedures were established.

In all measurements, the resolution of the spectrometer was about 0.75%. In each experimental run at each measured point, an effort was made to obtain at least 10^4 counts, without going to excessively long counting periods. A minimum counting period of 4 minutes was established so that timing errors were negligible.

The performance of the counter was carefully checked before each run for threshold, plateau length and slope, pulse height and general pulse quality, and background. Throughout the progress of a run, the counter pulses were monitored on an oscilloscope and the gas pressure was checked for constancy. The background counting rate was measured periodically.

At least two measurements of the magnetic field were made at each experimental point: one at the beginning and one near the end of the counting period. A third field measurement was made midway in counting periods longer than 20 minutes. The spread in field measurements was seldom greater than 0.04% and the average value was used in computation.

At the beginning of the run, the magnet was put through a prescribed hysteresis loop to establish the correct field shape. After the first run over the spectrum, the magnet was recycled and a second group of points was obtained as a check on source decay and general instrumental performance. No measured spectrum was regarded as acceptable for which there was any evidence of malfunctioning of the operation of the spectrometer and associated equipment during any portion of the run.

Preparation of Sources

The sources used in these experiments were of two types: liquid-deposited sources and sources deposited through thermal evaporation. Sources produced by liquid deposition are known to be less uniform because of crystalization and/or localized deposition during the drying process.[15] Various techniques have been used in an attempt to minimize these effects.[16,17]

For each liquid-deposited source, the material, in aqueous solution, was distributed "uniformly" on a Zapon backing (5μg/cm^2) over a well defined rectangular area (0.5 cm$\times$2.5 cm) which had been previously treated with a solution of 30 to 1 water to insulin.[16,18] The source was then dried in a desiccator jar under vacuum. When thoroughly dry, the source was covered with a thin Zapon film (1.5 μg/cm^2).

Some of the most definitive measurements of beta

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[13] L. M. Langer and R. D. Moffat, Phys. Rev. **80**, 651 (1950).

[14] L. E. Glendenin, Nucleonics **2**, No. 1, 12 (1948).

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[16] L. M. Langer, Rev. Sci. Instr. **20**, 216 (1949).

[17] Langer, Motz, and Price, Phys. Rev. **77**, 798 (1950).

[18] V. J. Schaefer and D. Harker, J. Appl. Phys. **13**, 427 (1942).

TABLE I. Sources of In^{114}.

Cyclotron bombard-ment	Source No.	Run	Source[a]	Source thickness (μg/cm^2)	Ground-state group $W_0(m_0c^2)$	%	"Inner group" $W_0(m_0c^2)$	%
1	1	1	Ld	190	4.837	94.1	2.681	5.9
	1	2	Ld	190	4.827	95.2	2.838	4.8
2	1	1	Ld	80	4.886	96.9	3.086	3.1
	2	1	Ld	70	4.875	97.1	3.031	2.9
3	1	1	Ld	60	4.883	97.1	2.751	2.9
4	1	1	Evap	15	4.896	97.0	2.610	3.0
	1	2	Evap	15	4.889	97.5	2.714	2.5

[a] Ld = Liquid-deposited sources: 5-μg/cm^2 Zapon backing; 1.5-μg/cm^2 Zapon source cover; filament grounded. Evap-Thermally evaporated source: 180-μg/cm^2 aluminum leaf backing; 1.5-μg/cm^2 Zapon source sover; contact grounded.

spectra have been made using sources produced by thermal vaccum evaporation techniques.[15,19] Very thin and uniform sources can be prepared in this manner.

After carrier-free separation, the source fraction sometimes contains some extraneous material. The differences in the rates of evaporation of the actual source material and the extraneous materials renders it possible through properly programmed thermal vacuum evaporation to effect distillation.[20] This distillation leads to a reduction in source thickness. Through preliminary tests, the evaporation program was established for distillation as well as the final evaporation of source material. A stainless steel mask with a rectangular opening (0.6 cm×2.5 cm) was used to define the area of source deposition.

Two means of preventing source charging were used: sources deposited on nonconducting backings are "grounded" by means of electron emission from the filament of a 2×2 vacuum tube[19] and sources deposited on conducting backings are grounded by direct contact.

Indium-114

The beta transition from the ground state of In^{114} to the ground state of Sn^{114} is a well known $\Delta I=1$, *no*, transition. The interaction forms capable of producing this transition in lowest order are tensor (T) and/or axial vector (A). In the absence of Fierz interference,[6] the spectrum is expected to have a "statistical shape," i.e., a linear Fermi-Kurie (F-K) plot.

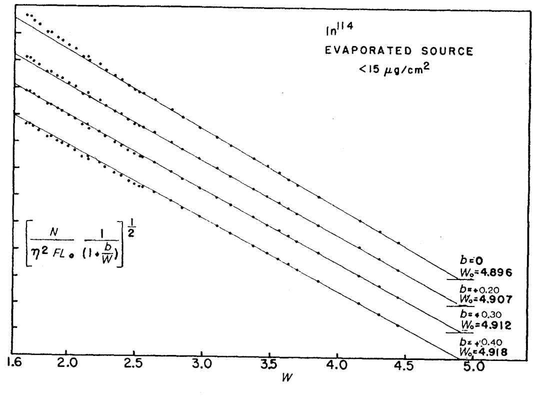

FIG. 1. F-K plots for In^{114} corrected with a shape factor $(1+b/W)$ for various values of b.

Five different sources were prepared from four bombardments with the 11-Mev deuteron beam from the Indiana University cyclotron. The target material was chemically pure Cd; the production reaction was $Cd^{113}(d,n)In^{114}$. After carrier-free chemistry,[2] relatively intense liquid-deposited or vacuum-evaporated sources were prepared.

In each of seven runs, the measurements were made from $W\approx 1.68\ m_0c^2$ to well beyond the endpoint of the In^{114} beta spectrum. Table I shows some of the pertinent features of each of the sources and the results obtained from the analysis of the measured spectra.

The data were corrected for decay using a half-life of 50 days. Repeat runs were made after intervals of 7 to 14 days. The data from repeated runs were consistent within counting statistics when corrected with this half-life. If beta activities with significantly different half-lives were present in the source, their presence would have been detected by the use of this procedure.

A conventional F-K plot was constructed with the aid of tables.[21] The high-energy portion of the F-K plot is essentially linear. The data in the energy region $W\gtrsim 2.85 m_0c^2$ were fitted with a least-squares straight line. F-K plots for each source exhibited a slight systematic upward deviation from linearity starting in the region $2.4m_0c^2<W<2.8m_0c^2$. The F-K plot for $b=0$ in Fig. 1 is a typical example. The root-mean-square percentage deviation of the points used in the determination of the least-squares line is 0.6% while on the basis of counting statistics a deviation of 0.5% would be expected.

This low-energy deviation was treated in the manner of a postulated second beta group and a conventional subtraction was made. The resulting points were least-squares fitted with a straight line and an "end point" was determined for this "inner group". The analysis in the manner of a second group allowed the computation of "relative intensities". The results of this analysis are

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[19] L. M. Langer and R. D. Moffat, Phys. Rev. **88**, 689 (1952).

[20] C. W. Sherwin, Rev. Sci. Instr. **22**, 339 (1951).

[21] *Tables for the Analysis of Beta Spectra*, National Bureau of Standards, Applied Mathematical Series No. 13 (U. S. Government Printing Office, Washington, D. C., 1952).

shown in Table I under the heading "Inner group". Accepting this analysis *only* as a measure of the deviation in the F-K plots from linearity, with the exception of the runs with the 190-μg/cm^2 source, the results are consistent.

The possible presence of other activities in the sources was carefully investigated. Detailed searches were made for internal conversion lines and gamma rays that would indicate the presence of radio-isotopes which could contribute to the In^{114} beta spectrum above $W=1.68m_0c^2$. Evidence for a true inner group of 3% intensity in In^{114} could not be found. The observed 0.7-Mev inner group in In^{114} is of such low intensity (0.09%) that its contribution can be neglected.[22,23]

Assuming no Fierz interference, several theoretical refinements were considered. The correction for the finite de Broglie wavelength[24,25] was made which decreased the deviation very slightly. The finite nuclear size correction[26,27] for an allowed transition with $Z=50$ is negligibly small and has a very weak energy dependence. The outer screening correction[21,28] is negligible over the portion of the spectrum investigated.

The method of Owen and Primakoff[29] for correcting for certain distortions of instrumental and experimental origin was considered. For this instrument and the sources used, this correction was negligible.

It was found that the In^{114} data corrected with a shape factor of the form $(1+b/W)$ yielded a linear F-K plot (Fig. 1). The least-squares lines were fitted to points with $W\geq 2.85m_0c^2$. A statistical analysis of the percentage deviations of the experimental points from linearity indicates that the best value of b would be in the range $0.2<b<0.3$.

Yttrium-90

The beta transition from the ground state of Y^{90} to the ground state of Zr^{90} is a once-forbidden, unique transition, $\Delta I=2$, *yes*,[30] which arises from the T and/or A interaction forms. When either T or A, but not both, is included in the law of beta decay, the once-forbidden, unique shape factor takes on the simple form $C_1 \propto (q^2L_0+9L_1)$. The terms L_0 and L_1 are the combinations of radial wave functions given by Greuling[31] and tabulated elsewhere[25] and q is the neutrino momentum. The momentum spectrum is given by

$$N(\eta) \propto F(Z,W)\eta^2(W_0-W)^2(q^2L_0+9L_1),$$

and contains no nuclear matrix elements in an essential manner.

Plassmann[1] analyzed beta spectra obtained from liquid-deposited sources of $Y^{90}(\approx 20\mu g/cm^2)$ on thin Zapon backings and found that the F-K plots corrected with the unique shape factor exhibited a slight systematic deviation from linearity. The deviation appeared to begin at $W\approx 2.0m_0c^2$. A search for evidence for an inner group gave negative results.

In this investigation, Y^{90} was separated from a $Sr^{90}-Y^{90}$ equilibrium solution obtained from Oak Ridge. Carrier-free Y^{90} fractions were obtained by using the separation of Chetham-Strode and Kinderman[32] which is given in greater detail elsewhere.[1] Five different sources were studied: three liquid-deposited sources ($\approx 35\mu$g/cm^2) on thin Zapon backings (3 μg/cm^2); one vacuum-evaporated source (<10 μg/cm^2) on a thin Zapon backing (<16 μg/cm^2); and one vacuum-evaporated source on a thin aluminum backing (180 μg/cm^2).

The measurements were made from window cutoff to well beyond the end point of the Y^{90} spectrum. The experimental points were corrected for decay, $t_{\frac{1}{2}}=65$ hours,[32,33] and background. Repeated runs on the same source, when corrected for decay with this half-life, were consistent within experimental errors. In addition, small samples of each separated fraction were taken for half-life measurements. No deviation from a 65-hour half-life could be found after a period of ten half-lives.

An F-K plot was made from the experimental data corrected with the unique shape factor. Both the liquid-deposited and evaporated sources gave plots which exhibited slight systematic deviations from linearity. Figure 2 shows a plot for each type of source. The straight line is a least-squares fit to all points for which $W\geqslant 3.0m_0c^2$.

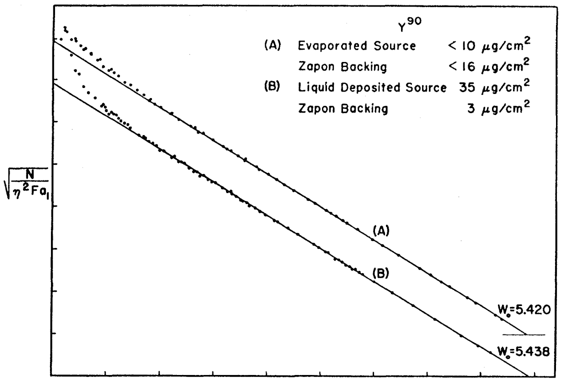

FIG. 2. F-K plots for Y^{90} comparing results obtained from liquid deposited and evaporated sources.

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[22] L. Grodzins and H. Motz, Phys. Rev. **102**, 761 (1956).

[23] Johns, Williams, and Brodie, Can. J. Phys. **34**, 147 (1956).

[24] M. E. Rose and C. L. Perry, Phys. Rev. **90**, 479 (1953).

[25] Rose, Perry, and Dismuke, Oak Ridge National Laboratory Report ORNL-1459, 1953 (unpublished).

[26] M. E. Rose and D. K. Holmes, Phys. Rev. **83**, 190 (1951).

[27] I. Malcom, Phil. Mag. **43**, 1011 (1952).

[28] J. R. Reitz, Phys. Rev. **77**, 10 (1950).

[29] G. E. Owen and H. Primakoff, Phys. Rev. **74**, 1406 (1948).

[30] *Nuclear Level Schemes, $A=40$—$A=92$*, compiled by Way, King, McGinnis, and van Lieshout, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C. 1955).

[31] E. Greuling, Phys. Rev. **61**, 568 (1942).

[32] A. Chetham-Strode, Jr., and E. M. Kinderman, Phys. Rev. **93**, 1029 (1954).

[33] R. W. Nottorf, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), National Nuclear Energy Series, Plutonium Project Record, Vol. 9, p. 682.

An analysis of this deviation in the manner of a postulated second group yielded essentially the same results as were reported by Plassmann,[1] that is, an intensity of about 1.5% and an endpoint $W_0 \approx 2.0 m_0c^2$. A comparison of the results of this type of analysis for the evaporated sources is shown in Table II. When the F-K plots resulting from these sources were normalized, no significant differences could be detected. This constitutes strong evidence against the backing leading to the distortion of the spectra over the energy range considered.

The use of the tabulated values for L_0 and L_1 presumably accounts for the effect of the finite de Broglie wavelength of the electron. The calculated finite-nuclear-size correction[26] indicates that this correction would be completely negligible for Y^{90}. The outer screening correction[21] is again very small. The "Owen-Primakoff" correction[29] was found to be negligibly small over the entire spectrum. The combined effect of these corrections resulted in only a very small change in the spectral shape and could not account for the observed deviation from linearity.

The possible existence of an inner group was further investigated using the magnetic spectrometer and scintillation techniques. No evidence was found for an inner group of the required intensity; however, evidence for an extremely weak beta transition to a 0+ excited state in Zr^{90} was found.[34,35] This excited state decays by pure radiationless transitions to the 0+ ground state.

The complete shape factor for a once-forbidden, unique transition including the T, A interference terms can be written as $C_1 \propto (q^2L_0+9L_1)+b(q^2P_0+9P_1)$. The combinations of radial wave functions P_0 and P_1 are given by Pursey[36] and tabulated elsewhere.[25] For $\alpha Z \ll 1$, the shape factor becomes $C_1 \propto (q^2+p^2)(1+b/W)$. It was found that correcting the Y^{90} data with a shape factor of this form produced a linear F-K plot. Figure 3 gives F-K plots for several values of the parameter b. The least-squares straight lines are fitted to all points with $W \geqslant 3.0\ m_0c^2$. The best value of b to yield a linear F-K plot is in the range $0.2 < b < 0.3$.

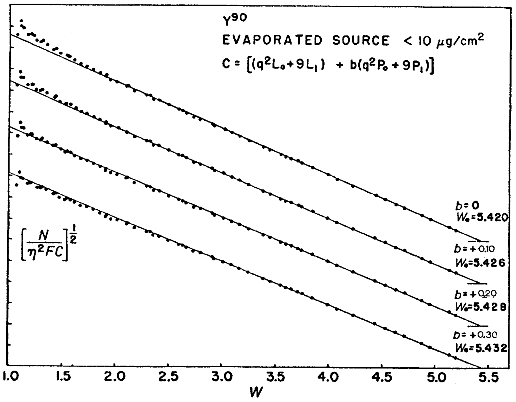

FIG. 3. F-K plots for Y^{90} corrected with a shape factor $[(q^2L_0+9L_1)+b(q^2P_0+9P_1)]$ for various values of b.

Phosphorus-32

The beta decay of P^{32} to S^{32} is an allowed, presumably l-forbidden transition.[4,5]

The sources used in this experiment were prepared from two shipments from Oak Ridge. It was found that both shipments contained a few percent P^{33} contaminant. Two evaporated sources ($<10\mu g/cm^2$) on aluminum backings (180 $\mu g/cm^2$) were used. A second run was made on one of the sources after an interval of 48 days and the resulting spectrum was compared with that obtained in the original measurement.

Measurements were made from window cutoff to well beyond the endpoint of the P^{32} beta spectrum. The data were corrected for source decay with a half-life of 14.3 days.[37] The maximum decay correction was less than 1.5%. A conventional F-K plot was constructed and is shown in Fig. 4. The points with $W \geqslant 2.1\ m_0c^2$ were used to obtain a least-squares straight line. This least-squares line was subtracted from the data and a second F-K plot made ("beta group" B). The data in "beta group" B with $1.5\ m_0c^2 < W < 2.0\ m_0c^2$ were fitted with a least-squares line. This second least-squares line was subtracted from the data and a third F-K plot made ("beta group" C). A least squares straight line was fitted to the data of "beta group" C for $1.15\ m_0c^2 \leqslant W \leqslant 1.4\ m_0c^2$. The analysis of the spectrum obtained from the same source 48 days later indicates that "beta group" B should be associated with P^{32} and "beta group" C is actually a P^{33} contaminant. The deviation associated with "beta group" B amounts to ~2% of the transitions associated with P^{32}.

TABLE II. Comparison of Y^{90} evaporated sources on aluminum and Zapon backings.

Backing	Source thickness	$(W_0)_1$[a] (m_0c^2)	"$(W_0)_2$"[b] (m_0c^2)	Intensity "inner group"
Zapon $<16\mu g/cm^2$	$<10\mu g/cm^2$	5.420	2.00	1.4%
Aluminum $180\mu g/cm^2$	$<16\mu g/cm^2$	5.428	2.06	1.5%

[a] $(W_0)_1$ = end point of ground-state group.
[b] "$(W_0)_2$" = "end point" of fictitious "inner group".

The small theoretical refinements considered for Y^{90} and In^{114} were considered for P^{32}. These corrections tend to reduce the deviation from linearity but are very small.

The P^{32} data corrected with a shape factor $(1+b/W)$ yielded a linear F-K plot (Fig. 5). The best value of the

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[34] K. W. Ford, Phys. Rev. **98**, 1516 (1955).
[35] Johnson, Johnson, and Langer, Phys. Rev. **98**, 1517 (1955).
[36] D. L. Pursey, Phil. Mag. **42**, 1193 (1951).
[37] J. G. Bayly, Can. J. Research **28A**, 520 (1950).

parameter b to yield a linear F-K plot is in the range $0.2<b<0.4$.

CONCLUSIONS

Each of the three isotopes investigated have one important feature in common—the only interaction forms which can contribute are pure Gamow-Teller. Consequently, in the absence of Fierz interference, the corrected Fermi-Kurie plots should be linear according to the present theory. Each experimental spectrum displayed a slight systematic deviation from linearity which could not be accounted for through the application of theoretical refinements. Instrumental and experimental effects which might lead to the distortion of the beta spectra were carefully considered. No evidence was found to indicate that the deviations from linearity are of an experimental or instrumental origin. The possibility of complex decays was investigated and in each case evidence for inner groups of the required intensity could not be found. It is therefore concluded that the measured spectra represent the undistorted beta distributions associated with the isotopes studied.

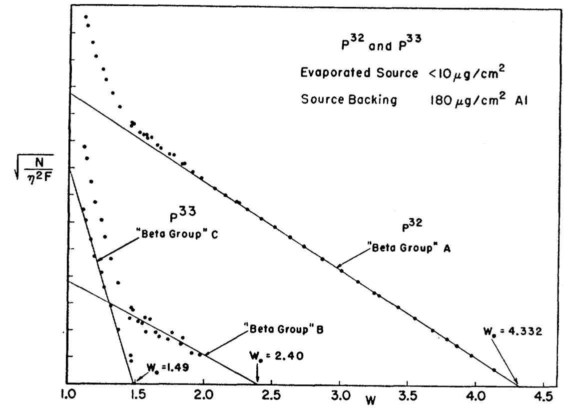

FIG. 4. F-K plot of P^{32} with P^{33} contaminant. "Beta group" *B* is used only as a measure of the deviation from linearity in the F-K plot.

It was found that a shape factor of the form $(1+b/W)$ would linearize the F-K plot of each of the three isotopes. In each case, the value of the parameter b to yield linear F-K plots is in the range $0.2<b<0.4$.

Since the conclusion of these experiments, several other investigators have studied two of these same spectra in search of small deviations. Pohm, Waddell, and Jensen measured the spectra of Y^{90} and P^{32} and reported no observable deviations from the statistical shape in either of these two isotopes.[3] Yuasa, Laberrique-Frolow, and Feuvrais have reported[38] a deviation at low energies in the Y^{90} spectrum similar to that observed in the present work. Porter, Wagner, and Freedman have reported[39] a deviation at low energies in the spectrum of P^{32}. Graham, Geiger, and Eastwood have measured the P^{32} beta spectrum in conjunction with their work on Pr^{144} and also report a deviation at low energy.[40] The deviation in the P^{32} shape factor observed by Graham *et al.* at low energy is somewhat greater than that observed by Porter *et al.* and is in closer agreement with that observed in the present work.

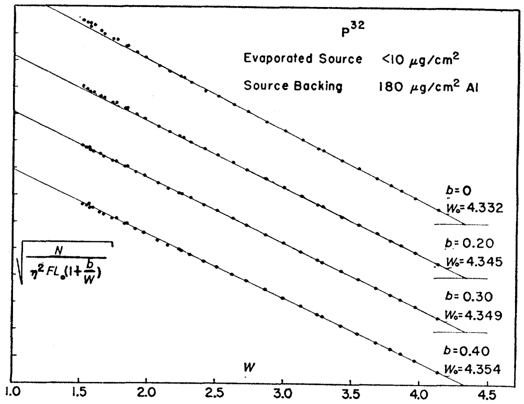

FIG. 5. F-K plots for P^{32} corrected with a shape factor $(1+b/W)$ for various values of b.

It was pointed out in the introduction that studies of a positron spectrum would be of great aid in interpreting the observed deviations in these electron emitters. It is of interest to determine whether such deviations are present in positron spectra and whether they are in the same or opposite direction to those in the negative electron spectra. A more complete discussion and interpretation of the results of these experiments is given in the following paper after the work on the positron spectrum of Na^{22} has been presented.[8]

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