Vanishing Fermi—Gamow-Teller mixing in the positron decay of ^{58}Co

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The asymmetry parameter, A_β, in the positron decay of polarized ^{58}Co has been measured to be $+0.341\pm0.013$. Assuming the standard T-invariant $V-A$ weak interaction theory, the Fermi to Gamow-Teller mixing ratio, $y=C_V M_F/C_A M_{GT}$, was determined to be -0.005 ± 0.008. The vanishing value of y is consistent with the isospin selection rule for the Fermi matrix element.

[RADIOACTIVITY ^{58}Co; measured $\beta(\theta)$, $\gamma(\theta)$; deduced source P, β asymmetry coefficient, Fermi to Gamow-Teller mixing ratio.]

I. INTRODUCTION

The study of the Fermi—Gamow-Teller mixing ratios, $y=C_V M_F/C_A M_{GT}$, in allowed isospin-hindered beta decays ($\Delta J=0$, $\Delta T=\pm1$) is of fundamental interest. A non-zero value of y in such decays implies the existence of an isospin impurity in the nuclear states, which may result either from electromagnetic effects or from the charge dependence of the nuclear forces.[1] Also, accurate measurements of y are crucial for experiments designed to test the validity of time-reversal invariance[2] in nuclear beta decay.

There are two major experimental methods that can be used to determine the value of y. One is the β-γ circular polarization correlation in which the coincidence between the β particle and the cascade γ ray is measured, with the simultaneous detection of the circular polarization of the γ ray. The other method is the β particle directional distribution from oriented nuclei in which the β particle emission intensity is measured at different angles with respect to the nuclear orientation axis. Both methods suffer from complicated experimental difficulties, but the nuclear orientation method has the advantage of having a much larger signal to background ratio than the circular polarization method. The previously reported values of y, mostly determined from the circular polarization method, have generally not been in good agreement.[3] For example, the two most recent measurements of y in ^{56}Co (Refs. 4 and 5) are only in fair agreement, and both of them are in serious disagreement with the most precise value previously reported.[6]

In this paper, we report an accurate determination of y for the β^+ decay in ^{58}Co using the nuclear orientation method. We have used a nuclear orientation facility designed particularly for the study of the directional distribution of β particles emitted by polarized nuclei. An outstanding feature of our nuclear orientation facility is the ability to polarize source nuclei without any significant deflection of the trajectories of the β particles emitted. In addition, we have investigated possible sources of systematic errors and have included the appropriate corrections in the data analysis. Our final result for ^{58}Co is

$$A_\beta=+0.341\pm0.013 ,$$

where the error includes both statistical and systematic contributions. Assuming the standard T-invariant V-A weak interaction theory, $y=-0.005\pm0.008$ for ^{58}Co.

II. BACKGROUND

The decay scheme of ^{58}Co is shown in Fig. 1.[7] The β decay under study is the positron transition from an initial state of 2^+ to a final state of 2^+ with an end-point energy of 474 keV. In addition, the cascade 811 keV γ rays emitted from 2^+ to 0^+ with pure $E2$ multipolarity were also measured to determine the magnitude and direction of nuclear polarization.

Following the formulations and notations given by Krane,[8] the directional distribution of the 811 keV γ rays emitted by polarized ^{58}Co nuclei can be written as

$$W_\gamma(\theta)=1-0.2975Q_2B_2P_2(\cos\theta)+0.7055Q_4B_4P_4(\cos\theta) . \quad (1)$$

Here Q_2 and Q_4 are the source-detector geometrical correction factors, B_2 and B_4 are, respectively, the nuclear orientation parameters of order 2 and 4, P_2 and P_4 are the ordinary Legendre polynomials, and θ is the angle between the radiation emission direction and the nuclear polarization axis. The coefficients -0.2975 and 0.7055 depend on the angular momenta as well as the multipolarities of the radiation fields involved and are calculated based on the decay scheme shown in Fig. 1.

The directional distribution for β^+ particles emitted by polarized ^{58}Co nuclei can be written as[8]

$$W_\beta(\theta,v)=1+Q_1B_1\frac{1.1549y-0.2357}{1+y^2}\frac{v}{c}\cos\theta , \quad (2)$$

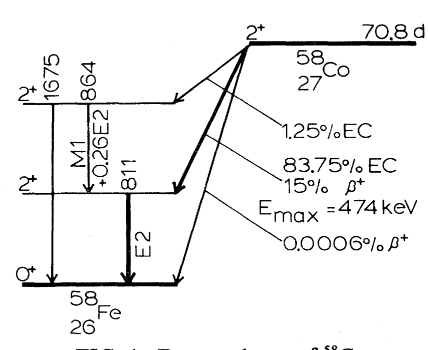

FIG. 1. Decay scheme of ^{58}Co.

where

$$y = C_V M_F / C_A M_{GT} \ . \tag{3}$$

Here Q_1 and B_1 are the geometrical correction factor and the nuclear orientation parameter (of order 1), respectively, v/c is the ratio of the β^+ particle velocity to the speed of light, C_V and C_A are the vector and axial-vector coupling constants, and M_F and M_{GT} are the Fermi and Gamow-Teller matrix elements, respectively. As usual, the *V-A* interaction, maximal parity violation, and time-reversal invariance have been assumed.

In the literature,[9] Eq. (2) is also written as

$$W_\beta(\theta,v) = 1 + Q_1 A_\beta P \frac{v}{c} \cos\theta \ , \tag{4}$$

where A_β is the β-asymmetry parameter, and for ^{58}Co,

$$A_\beta = \frac{0.3333 - 1.6333y}{1+y^2} \ . \tag{5}$$

Here P is the nuclear polarization and is related to B_1 by

$$P = -0.7071 B_1 \ . \tag{6}$$

In this experiment, the measured 811 keV γ ray anisotropy is used to determine the values of B_2 and B_4 as well as the direction of the nuclear polarization axis. Then, the tables in Ref. 8 can be used to obtain the value of B_1 (and P) under the constraint that all the cobalt nuclei have the same hyperfine field and temperature at their nuclear sites.

III. EXPERIMENTS

The experimental apparatus developed at Columbia for the study of β particles emitted by polarized nuclei is described in detail elsewhere.[10] Here, we will only briefly review some of the important general features of this nuclear orientation facility. The cooling power was provided by a ^{3}He/^{4}He dilution refrigerator that offered excellent temperature stability (1% fluctuation over months). This feature was critical for the desired stability of nuclear polarization P throughout the entire data acquisition period. A Si(Li) detector (80 mm$^2\times$5mm) was mounted inside the cryostat to detect the β particles and a Ge(Li) detector (80 cm^3) outside the Dewar was used to measure the 811 keV γ rays. Both detectors had excellent energy resolutions ($\simeq$5 keV) in the energy region of interest. An aluminum shutter with sufficient thickness to stop all β particles was mounted inside the cryostat between the source and the β particle detector. Consequently, the unwanted γ background spectrum, which constituted one of the most serious problems in previous, similar studies, could be measured and, consequently, removed during data analysis.

Permendur (49% Fe, 49% Co, 2% V) was chosen as the ferromagnetic host primarily because it could be saturated in a small applied field of only $\simeq$100 Oe and was magnetically soft and isotropic when properly annealed. Also, Co nuclei in permendur experience a large hyperfine field ($\simeq$280 kG), and are polarized at dilution refrigerator temperatures.

Two independent orthogonal magnetic loops were used to generate the polarizing field parallel to the plane of the source foil. The direction of the polarizing field and, consequently, the nuclear polarization axis could be rotated 360° in the source foil plane by adjusting the coil currents in both loops. By using permendur and the double magnetic loops, the stray magnetic fields in the region between the source and the β detector were significantly reduced and confined. As a result, accurate measurements of the β particle (> 100 keV) intensity at almost any angle from the nuclear polarization axis were possible with less than 2° deflection of the β particle trajectories. A drawing of the tail assemblies attached to the dewar and the ^{3}He/^{4}He refrigerator is shown in Fig. 2.

The preparation of permendur host foils that simultaneously were magnetically soft and isotropic, and had ^{58}Co atoms diffused into lattice sites within 1 or 2 μ of the foil surface, was one of the most critical tasks of the experiment. Previous β directional distribution studies and Monte Carlo calculations showed that the ^{58}Co activity must be within 1 or 2 μ of the surface of the permendur host foil in order to reduce the effects of source thickness on the measured value of A_β.

The source preparation procedure used in this study consisted of the following major steps. (1) First, 25 μ thick permendur was cut in the shape of a cross and the tabs were bent so that the permendur could be attached to the double magnetic loops (see Fig. 2). (2) Next, the ^{58}Co activity was electroplated onto the shaped permendur crosses using a procedure based on a method described by Joshi and Roy.[11] (3) The electroplated permendur was then heated in a closed H_2 gas system using the following thermal-annealing recipe: Heat the source foil to 600 °C from room temperature over a period of about an hour; keep at 600 °C for half an hour; heat the source foil from 600 °C to 850 °C over a period of half an hour; keep at

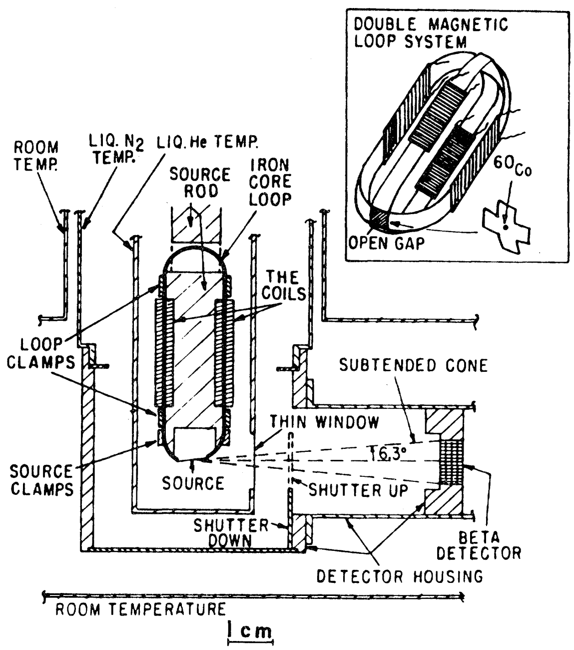

FIG. 2. Cross-sectional view of the ^{3}He/^{4}He dilution refrigerator tail section used in the β asymmetry measurements. The permendur source foil is clamped to the double magnetic loop system in the region labeled "source."

850 °C for five minutes; pull the oven away to cool the source quickly down to room temperature; heat the foil from room temperature to 500 °C over a period of about an hour; keep at 500 °C for about 50 hours[12]; pull the oven away to cool the source back down to room temperature. (4) After the electroplating and diffusion were completed, the sources were given a short electropolish to remove any undiffused activity from the surface. (5) The last step in the source preparation was to electroplate copper and gold onto the tabs of the shaped permendur crosses in order to more effectively transfer the heat deposited in the foil by the decay of the source nuclei. The gold plating was applied over the copper-plated areas in order to prevent surface oxidation and to lower the thermal resistance between the source foils and the source rod at the clamping points. The center of the permendur cross, where the cobalt was diffused, was not electroplated with either copper or gold because of the inverse magnetostriction of the source foil. When mounted the tabs of the permendur cross were thermally anchored to the source rod with gold-plated copper clamps. The resulting source activity was in the region of 10 to 20 μCi.

Nuclear magnetic resonance on oriented nuclei (NMR-ON) techniques were employed to study a ^{58}Co source thermally annealed as described above. A single hyperfine field of $\simeq$280 kG for Co in permendur was observed, which was a necessary condition for the accurate determination of nuclear polarization P from the measured γ ray data. Also, the depth of the diffusion of the activity into the source foil was analyzed using electropolishing techniques, and was found to follow approximately a semi-Gaussian distribution with a mean depth of $\simeq 1\ \mu$.

IV. DATA ACQUISITION

Four independent runs were carried out on the same ^{58}Co source. The general data acquisition procedure was the same for all four runs. In each run, β and γ spectra were measured at four different polarization angles, which were obtained by applying 250 mA currents to the coils of the double magnetic loop in such a way that the applied magnetizing fields at the permendur foil source were at 10°, 190°, 90°, and 270° from the β detector axis. For each angle θ, eight different spectra were accumulated: (1) $G^{\rm cold}_{\rm close}$ (θ_γ), (2) $S^{\rm cold}_{\rm close}$ (θ_β), (3) $S^{\rm cold}_{\rm open}$ (θ_β), (4) $S^{\rm cold}_{57}$ (θ_β), (5) $G^{\rm warm}_{\rm close}$ (θ_γ), (6) $S^{\rm warm}_{\rm open}$ (θ_β), (7) $S^{\rm warm}_{\rm close}$ (θ_β), and (8) $S^{\rm warm}_{57}$ (θ_β). Here "S" and "G" refer to the Si(Li) and the Ge(Li) detectors with which the spectra were taken; "close" and "open" refer to the position of the aluminum shutter mounted between the source and the Si(Li) detector; "cold" and "warm" refer to the temperature of the source nuclei where "cold" spectra were taken with the ^{58}Co nuclei polarized at a temperature of about 0.020 K and "warm" spectra were taken with the ^{58}Co nuclei unpolarized at 4.2 K; θ_β and θ_γ refer to the angles between the nuclear polarization axis and the axes of the Si(Li) detector and the Ge(Li) detector, respectively. In our experimental geometry, θ_β and θ_γ were related by

$$|\cos\theta_\beta| = (1-\cos^2\theta_\gamma)^{1/2}\cos 10° . \tag{7}$$

Additional γ ray spectra were taken at the four polarization settings by applying a magnetizing current of 1 A to the coils of the double magnetic loop. These γ spectra were used for the determination of the magnitude of the nuclear polarization. However, β spectra were not taken when the 1 A currents were applied since the deflections of the β particle trajectories due to the magnetic fields would exceed 2°.

Throughout the data acquisition procedure, the stability of the β particle detector electronics was continuously monitored by examining the on-line printouts of a reference pulser peak fed into the Si(Li) detector and accumulated in the β spectra above the end point. Also, the same procedure of applying and changing the magnetizing currents was carefully followed for both the "cold" and "warm" data. Since the cold and the warm data were taken under experimental conditions as nearly identical as possible, any geometrical and magnetic effects can be minimized by normalizing the cold spectra by the corresponding warm spectra.

A typical accumulated shutter-open Si(Li) detector spectrum and the corresponding shutter-closed spectrum taken at the same temperature and the same angle are superimposed and shown in Fig. 3. The γ ray background in the β detector is clearly known with excellent energy resolution. The small difference between the two spectra after the end-point energy 474 keV is mainly due to the Compton scattering of the 511 keV annihilation photons in the detector and can be corrected for during data analysis.

V. DATA ANALYSIS

A. γ ray data analysis

For each angle the experimental value of the γ ray directional distribution was determined as the following:

$$W^{\rm ex}_\gamma(\theta_\gamma) = \frac{N^{\rm cold}(\theta_\gamma)}{N^{\rm warm}(\theta_\gamma)} . \tag{8}$$

Here $N^{\rm cold}$ and $N^{\rm warm}$ are, respectively, the areas under the 811 keV γ ray peak in the $G^{\rm cold}_{\rm close}$ and $G^{\rm warm}_{\rm close}$ spectra mentioned in the previous section, and have been corrected for the ^{58}Co decay and dead time of the electronics.

The values of $W^{\rm ex}_\gamma$ (θ_γ) obtained above were then directly substituted into the theoretical expression Eq. (1) to

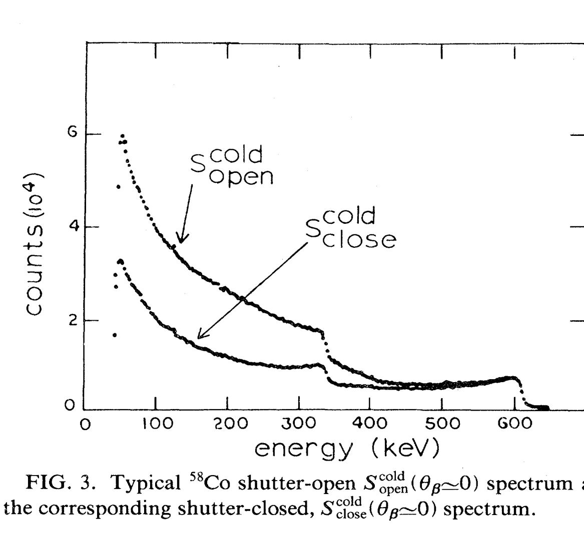

FIG. 3. Typical ^{58}Co shutter-open $S^{\rm cold}_{\rm open}(\theta_\beta \simeq 0)$ spectrum and the corresponding shutter-closed, $S^{\rm cold}_{\rm close}(\theta_\beta \simeq 0)$ spectrum.

determine the nuclear orientation parameters B_2 and B_4 as well as the values of $\cos^2\theta_\gamma$. The resulting values of B_2 and B_4 were then used to obtain the values of B_1 and the nuclear polarization P from the tables prepared by Krane.[8] The corresponding value of $\cos\theta_\beta$ was also determined from the $\cos^2\theta_\gamma$ result and the known coil current directions. The polarization axis was taken along the hyperfine field direction which is opposite to the direction of the magnetization of the permendur foil.

B. β data analysis

The four spectra taken with the Si(Li) detector, $S^{\rm cold}_{\rm open}$, $S^{\rm cold}_{\rm close}$, $S^{\rm warm}_{\rm open}$, and $S^{\rm warm}_{\rm close}$, at the same angle θ_β, were used to determine the experimental value of the β particle directional distribution, $W^{\rm ex}_\beta(\theta_\beta)$. First these four spectra were weighted properly to account for the ^{58}Co decay, and then were shifted to a common energy scale using results from the ^{57}Co calibration spectra, $S^{\rm cold}_{57}(\theta_\beta)$ and $S^{\rm warm}_{57}(\theta_\beta)$, and the pulser locations in each spectrum as described earlier. The detector electronics were found to be extremely stable throughout the entire experiment, and the observed relative energy shifts were negligibly small.

Following the adjustments described above, the pure β spectra were then obtained using

$$S^{\rm cold}_\beta(\theta_\beta,n)=S^{\rm cold}_{\rm open}(\theta_\beta,n)-a\times S^{\rm cold}_{\rm close}(\theta_\beta,n)$$

and

$$S^{\rm warm}_\beta(\theta_\beta,n)=S^{\rm warm}_{\rm open}(\theta_\beta,n)-a\times S^{\rm warm}_{\rm close}(\theta_\beta,n)\ , \tag{9}$$

where $a=1.031$ corrects for the attenuation of the 811 keV γ rays by the aluminum shutter and n is the channel number index. These β spectra were, however, distorted and had to be corrected for the following experimental effects before the asymmetry parameter A_β and the Fermi to Gamow-Teller mixing ratio, y, were deduced.

1. ^{60}Co contamination

A small ^{60}Co contamination was found in our source at the end of the experiment, and the observed intensity of the 1173 keV γ ray from ^{60}Co was then 0.5% of that of the ^{58}Co 811 keV γ rays. Since the ^{60}Co β asymmetry parameter is about three times larger in magnitude than that of ^{58}Co but has the opposite sign, this contamination would tend to reduce the measured ^{58}Co asymmetry parameter if not corrected for during data analysis.

To remove the ^{60}Co impurity from an observed β spectrum, the β contamination ratio R_β was first determined using the measured γ contamination ratio and the information on branching ratios for the two isotopes from Ref. 7. Since ^{58}Co and ^{60}Co have different decay constants, the value of R_β was time dependent and was determined for each $S_\beta(\theta_\beta,n)$ at its acquisition time. The ^{60}Co contribution in each $S^{\rm warm}_\beta(\theta_\beta,n)$ spectrum was calculated from the Fermi β theory and then normalized using

$$\sum_n {}^{60}S^{\rm warm}_\beta(n)=\frac{R_\beta}{1+R_\beta}\sum_n S^{\rm warm}_\beta(\theta_\beta,n)\ , \tag{10}$$

where ${}^{60}S^{\rm warm}_\beta(n)$ is the simulated ^{60}Co spectrum, and n is the channel number. In the warm, unpolarized case, direct subtraction of ${}^{60}S^{\rm warm}_\beta(n)$ from $S^{\rm warm}_\beta(\theta_\beta,n)$ then yielded the pure ^{58}Co spectrum ${}^{58}S^{\rm warm}_\beta(\theta_\beta,n)$ or

$${}^{58}S^{\rm warm}_\beta(\theta_\beta,n)=S^{\rm warm}_\beta(\theta_\beta,n)-{}^{60}S^{\rm warm}_\beta(n)\ . \tag{11}$$

For the cold, polarized case, the corresponding ^{60}Co spectrum for each polarization angle θ_β was calculated using

$${}^{60}S^{\rm cold}_\beta(\theta_\beta,n)={}^{60}S^{\rm warm}_\beta(n)\left[1+{}^{60}A_\beta\,{}^{60}P\frac{v(n)}{c}\cos\theta_\beta\right]\ , \tag{12}$$

where ^{60}P and $\cos\theta_\beta$ were determined from the ^{58}Co γ anisotropy data; ${}^{60}A_\beta$ was set equal to -1 in agreement with our recent observations[13]; ${}^{60}S^{\rm warm}_\beta(n)$ was the simulated ^{60}Co Fermi β spectrum at the acquisition time of $S^{\rm cold}_\beta(\theta_\beta,n)$, and $v(n)/c$ was the velocity at channel n divided by the speed of light c. This ${}^{60}S^{\rm cold}_\beta(\theta_\beta,n)$ spectrum was then subtracted from the observed $S^{\rm cold}_\beta(\theta_\beta,n)$ spectrum to yield the cold, pure ^{58}Co β spectrum, ${}^{58}S^{\rm cold}_\beta(\theta_\beta,n)$; that is,

$${}^{58}S^{\rm cold}_\beta(\theta_\beta,n)=S^{\rm cold}_\beta(\theta_\beta,n)-{}^{60}S^{\rm cold}_\beta(\theta_\beta,n)\ . \tag{13}$$

2. Radiation damage in the Si(Li) detector

Radiation damage effects by the positrons absorbed in the Si(Li) detector were observed by comparing spectra taken under identical conditions throughout the experiment. After decay corrections, the counts in each of the energy bins decreased slowly as the exposure time of the detector to positrons increased. However, if the detector bias was reduced to zero followed by a small forward biasing, the detector resumed its original characteristics.

Detailed quantitative analysis showed that, in the energy range between 200 and 300 keV (to be used later in the extraction of the β asymmetry parameter), this effect could be accurately described in terms of an energy independent deterioration parameter $\epsilon(T)$ defined simply as

$$\epsilon(T)=e^{-\sigma T}\ , \tag{14}$$

where T is the detector exposure time to the positrons from the source. The value of σ determined from all available data was

$$\sigma=0.000\,37\pm0.000\,07/\mathrm{h}\ .$$

Consequently, for each β spectrum, S_β, a correction was made using

$$S^A_\beta=\frac{S_\beta}{\epsilon(T)}\ , \tag{15}$$

where T was the cumulative shutter-open time before the collection of S_β, and S^A_β is the β spectrum *after* the correction.

Typical Si(Li) β^+ count rates were a few hundred per second, and the total exposure time between warming of the detector was 20–30 days. The β^+ particles were all stopped in the front part of the Si(Li) detector. However, γ rays, which deposited energy throughout the detector, were used for energy calibration. Consequently, since the intensity of the β^+ spectrum falls rapidly with increasing energy, a shift to lower energy of the entire β^+ spectrum proportional to the β^+ exposure would give a decrease in the count rate in our energy bins proportional to the β^+ exposure. Such a shift could occur if the Si(Li) β^+ output pulses changed their shape with increased detector exposure, or if some of the energy deposited by the β^+ particles was not collected. However, the change in the Si(Li) detector's response to the β^+ particles was so small that we were unable to establish its origin.

3. Positron annihilation

After being stopped in the Si(Li) detector, the positrons from ^{58}Co annihilate and two oppositely directed 511 keV photons are emitted. Subsequently, these 511 keV photons may Compton scatter before leaving the Si(Li) detector and therefore deposit some energy in the detector. As a consequence, the detected β spectrum would have fewer counts in the low-energy region and more counts in the high-energy region than the original incident β spectrum. From the geometry of the detector and the Compton effect cross sections we estimated that 12% of the incident β particles with energy E_β would be recorded into channels with energies larger than E_β. To correct for this effect, we used the Klein-Nishina formula[14] to calculate the probability $P(n \rightarrow m)$ that an incident β particle with energy $E(n)$ would have been misrecorded into channel m,

$$E(m) > E(n)$$

due to the Compton scattering of the annihilation photons. Each β spectrum was then corrected, starting from the first channel ($n=1$), using

$$S_\beta^A(n) = \frac{S_\beta(n) - 0.12 \times \sum_{l<n} P(l \rightarrow n) S_\beta^A(l)}{0.88} , \tag{16}$$

where $S_\beta(n)$ and $S_\beta^A(n)$ referred to spectra *before* and *after* the correction, respectively.

4. Detector backscattering

It is well known that the incident β particles on a Si(Li) detector may be backscattered and do not deposit their full energies in the detector. Consequently, a distortion is generated in the observed β spectrum in which the low-energy region is overcounted and the high-energy region is undercounted.

Following the procedure described by Charoenkwan,[15] a correction was made, starting from the channel n_m corresponding to the maximum β particle energy, for each β spectrum as follows:

$$S_\beta^A(n) = \frac{S_\beta(n) - \sum_{l=n+1}^{n_m} [B_c S_\beta^A(l)]/[E(l-1)/\Delta E]}{(1-B_c)} . \tag{17}$$

Here the backscattering coefficient B_c was assumed to be independent of the incident β particle energy and, for the β energy region above 200 keV, was estimated to be 0.17 for our source-detector geometry;

$$\Delta E = E(l+1) - E(l)$$

and is the energy separation between the two neighboring channels $l+1$ and l. $S_\beta^A(n)$ is the spectrum after the correction.

After all the corrections described above were made on each individual β spectrum, the experimental value of the beta directional distribution, $W_\beta^{\text{ex}}(\theta_\beta,n)$, was then calculated by normalizing the cold, polarized spectra with respect to the corresponding warm, unpolarized spectra at each energy channel n,

$$W_\beta^{\text{ex}}(\theta_\beta,n) = \frac{S_\beta^{\text{cold}}(\theta_\beta,n)}{S_\beta^{\text{warm}}(\theta_\beta,n)} . \tag{18}$$

Also, the experimental β asymmetry spectra $A_\beta^s(\theta_\beta,n)$ were determined from

$$A_\beta^s(\theta_\beta,n) = \frac{W_\beta^{\text{ex}}(\theta_\beta,n) - 1}{v(n)/c} , \tag{19}$$

where $v(n)$ is the velocity at channel n. In Fig. 4, $A_\beta^s(\theta_\beta,n)$ from a typical data set are plotted versus the energy for three different polarization angles. As shown in the energy region between 200 and 300 keV, values of $A_\beta^s(\theta_\beta,n)$ for all three angles are virtually independent of energy. Also the measured β asymmetries are approximately equal in magnitude but opposite in sign at opposite polarization angles (20° and 200°) and are vanishingly small at the 90° polarization angle. Similarly, the β asymmetries for $\theta_\beta = 270°$ were also vanishingly small. These results are all in excellent agreement with the theoretical expression given in Eq. (4). Although the negligible β asymmetries observed at 90° and 270° polarization angles are not useful for the determination of y, they nevertheless provide a strong demonstration that serious systematic errors have been minimized.

VI. RESULTS AND DISCUSSION

The experimental results of all four independent runs are summarized in Table I. The values of P and $\cos\theta_\beta$ listed were determined from the γ ray analysis. The $A_\beta^s(\theta_\beta)$ values listed were obtained by averaging $A_\beta^s(\theta_\beta,n)$ defined in Eq. (19) over the β energy range, 200—300 keV. The errors listed on the $A_\beta^s(\theta_\beta)$ values include contributions from statistics, ^{60}Co contamination, detector deterioration, positron annihilation in the detector, and detector backscattering. The β asymmetry parameters A_β listed in Table I were obtained using

$$A_\beta = \frac{A_\beta^s(\theta_\beta)}{F_m Q_1 P \cos\theta_\beta} . \tag{20}$$

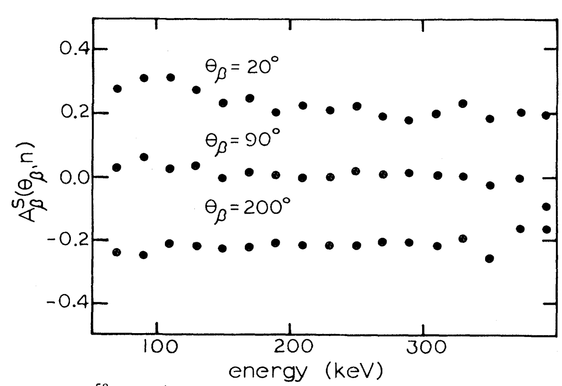

FIG. 4. ^{58}Co β^+ asymmetry versus the β^+ energy. The angles listed are those between the nuclear polarization axis and the β detector axis.

TABLE I. ^{58}Co experimental results. The weighted average of $A_\beta=0.341\pm0.013$, where the estimated error associated with an individual measurement is used.

Run	P	$\cos\theta_\beta$	$A_\beta^s(\theta_\beta)$	A_β
1	0.701 ± 0.004	-0.944 ± 0.006	-0.209 ± 0.005	0.334 ± 0.011
		0.950 ± 0.006	0.211 ± 0.006	0.335 ± 0.012
2	0.715 ± 0.006	-0.932 ± 0.010	-0.220 ± 0.007	0.348 ± 0.014
		0.927 ± 0.010	0.231 ± 0.007	0.367 ± 0.015
3	0.718 ± 0.006	-0.931 ± 0.010	-0.230 ± 0.007	0.363 ± 0.014
		0.931 ± 0.010	0.224 ± 0.007	0.354 ± 0.015
4	0.713 ± 0.006	-0.935 ± 0.011	-0.187 ± 0.008	0.296 ± 0.015
		0.939 ± 0.011	0.208 ± 0.008	0.328 ± 0.015

Here Q_1 is the solid angle correction factor defined earlier and, for our experimental configuration, it is 0.997. F_m is a correction factor for the effects of β particle scattering in the permendur source foil. Monte Carlo simulations based on the modified Mott-Born scattering formulas[16] were performed in order to estimate the attenuation of the measured value of A_β due to scattering of the β^+ particles in the permendur source foil. Input to the Monte Carlo program included our geometrical configuration, the source profile in the permendur foil, and the scattering cross sections for both small-angle and large-angle scattering of the positrons emitted by ^{58}Co. The Monte Carlo results showed that in the energy region between 200—300 keV, the value of A_β measured in our experimental arrangement would be $5\%\pm2\%$ less than in the case of a zero thickness source host foil, and

$$F_m=0.95\pm0.02 .$$

The final value used for A_β is then the weighted average of all the values of A_β listed in Table I. The relative sizes of the errors that contribute to the uncertainty of A_β are indicated in Table II. We find

$$A_\beta=0.341\pm0.013 ,$$

and the Fermi—Gamow-Teller mixing ratio is therefore

$$y=-0.005\pm0.008 .$$

Our result is compared with that of previous workers in Fig. 5. We are in excellent agreement with the two latest measurements[6,17] and in fair agreement with some of the earlier, less accurate measurements.[3] The vanishingly small value of y obtained indicates that the Fermi contribution is strongly suppressed in the positron decay of ^{58}Co consistent with isospin selection rules. The deduced Fermi matrix element[3] from our result is

$$|M_F|=(0.19^{+0.32}_{-0.19})\times10^{-3} ,$$

which implies an isospin impurity

$$|\alpha|=(0.08^{+0.13}_{-0.08})\times10^{-3}$$

and a charge-dependent nuclear matrix element

$$|\langle H_{\rm cd}\rangle|=(0.52^{+0.85}_{-0.52})\ \text{keV} .$$

TABLE II. Experimental errors in the determination of A_β.

Source of error	Percent error (%)
Statistics (counts)	2—4
Polarization (P)	0.6—1.0
Geometry ($\cos\theta_\beta$)	0.6—1.1
^{60}Co impurity[a]	1.7
Detector deterioration[a]	0.8
Positron annihilation[a]	0.2
Detector backscattering[a]	0.2
Scattering in the source[a]	2

[a]The estimated error is approximately one-third of the total change in A_β after the correction.

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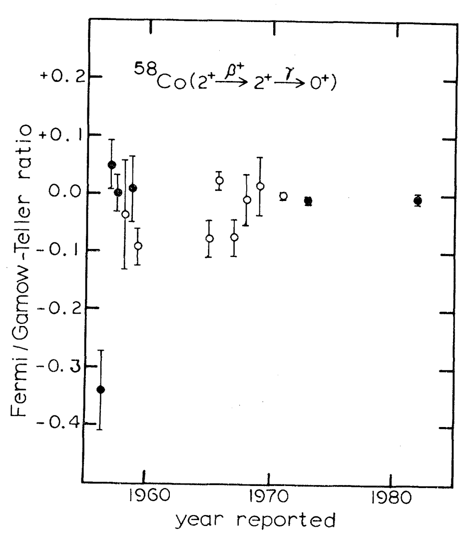

FIG. 5. Fermi—Gamow-Teller measurement results for ^{58}Co. The solid points were determined using the β asymmetry nuclear orientation method and the open points were obtained with the β-γ circular polarization correlation method. The data points are tabulated in Ref. 3.

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