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SUMMARY: The depolarization of high energy positrons degraded to rest in matter has been measured using the lifetime distribution of positronium in a magnetic field as a polarization analyzer. Positron beams with initial energies between 0.4 MeV and 24 MeV were investigated. The use of a linear accelerator to produce a high energy polarized positron beam is described. The results show that 12 MeV positrons are 79 ± 12% depolarized in being degraded to rest. For this reason, the polarization analyzer using positronium in a magnetic field does not appear to be useful for high energy applications.

1. INTRODUCTION

One of the characteristic features of parity violation in beta decay is the longitudinal polarization of positrons and electrons emitted from an unpolarized source. In the case of nuclear beta decay, this effect has been observed in many detailed and elegant experiments. A review article on the subject has been written by Page. (1) Currently there is great interest in the determination of the polarization of electrons and positrons emitted in the beta decay of elementary particles. The experimental situation, however, is considerably less favorable to such investigations because of the greater energy of the electrons and positrons, and because of the limited intensities available. For these reasons, the only elementary particle process studied at present is the electron and positron polarization in μ decay. (2,3,4,5) In these experiments, polarization has been measured by observing the interactions of beta rays with polarized electrons in magnetized iron. Because the electron polarization in saturated iron is only 2/26, the observable polarization dependent effects are small.

In a recent experiment (6) positron polarization from μ decay was measured by a method of detection in which polarization is detected after positrons have been brought to rest in a degrader.

1. Lorne A. Page, Annual Review of Nuclear Science 12, 43 (1962)
2. Macq, Crowe, and Haddock, Phys. Rev. 112, 2061 (1958)
3. Culligan, Frank, and Holt, Proc. Phys. Soc. (London) 73, 169 (1959)
4. Buhler, Cabbibo, Fidecaro, Massam, Schneegrans, and Zichichi, Phys. Letters 7, 368 (1963)
5. Duclos, Heintze, De Rujula, and Soergel, Phys. Letters 9, 62 (1964)
6. Dick, Feurvais, and Spighel, Phys. Letters 7, 150 (1963)

In this method, the direct interaction of the positron magnetic moment with a laboratory produced magnetic field is observed. At low energies the polarization dependent effect is large and positrons are detected with good efficiency. This method was first used by Page (7), and more recently by Bisi (8), and Dick (9).

For high energy applications it is necessary that the depolarization mechanism in the degrading process be understood. In the present work we describe measurements of the depolarization of a positron beam degraded to rest from energies between 0.4 and 24 MeV.

7. L. A. Page and M. Heinberg, Phys. Rev. 106, 1220 (1957)
8. Bisi, Fiorentini, Gatti, and Zappa, Phys. Rev. 128, 2195 (1962)
9. Dick, Feuvrais, Madansky, and Telegdi, Phys. Letters 3, 326 (1963)

II. POLARIZATION ANALYZER

The polarization analyzer used is the effect of the positron polarization on the time distribution of positronium decays in a magnetic field. In this process it is the projection of the positron spin on the magnetic field direction which is measured. When a polarized positron is captured by an unpolarized electron to form positronium, the system rapidly falls into the lowest 1S state; but to a large extent the relative spin state of the positron and electron is preserved. Since transitions between the singlet and triplet sublevels of the ground state are very slow, the positronium annihilates in a mode which depends on the relative spin state of the electron and positron before capture.

The relevant parameter in describing the polarization effect is the ratio, x , of the positron coupling with the external magnetic field to the ground state hyperfine splitting of positronium, $\Delta\omega$:

$$x = \frac{4|\mu_{e^+}|\ |H|}{\Delta\omega}$$

To simplify the following discussion, the parameter y has been used.

$$y = \frac{x}{2+\sqrt{4+x^2}}$$

The wave functions of positronium in an external magnetic field are obtained from the matrix which diagonalizes the Hamiltonian:

$$\mathcal{H} = \Delta\omega\ \vec{\sigma}_+\cdot\vec{\sigma}_-\ -g_+\mu_0\vec{\sigma}_+\cdot\vec{H}\ -g_-\mu_0\vec{\sigma}_-\cdot\vec{H}$$

In this expression, only the spin part of the ground state has been considered. The effect of the external magnetic field, H , is to mix the states with $M = 0$, i.e. singlet state with the $M = 0$ triplet state.

The four positron-electron spin states in the positronium ground state in a constant magnetic field are as follows:

Quasi Triplet: $\psi_{10} = \frac{1}{\sqrt{1+y^2}} \left\{ |10> - y\, |00> \right\}$

Triplet: $\psi_{11} = |11>$

Triplet: $\psi_{1-1} = |1-1>$

Quasi Singlet: $\psi_{00} = \frac{1}{\sqrt{1+y^2}} \left\{ |00> + y\, |10> \right\}$

The above expansions were made in terms of the usual $|JM>$ angular momentum eigenfunctions with the z axis chosen parallel to the magnetic field direction.

The relative populations of the states when a polarized positron beam, $|\frac{1}{2}\, \frac{1}{2}>$, forms positronium with unpolarized electrons are:

ψ_{11}	ψ_{10}	ψ_{1-1}	ψ_{00}
$\frac{1}{2}$	$\frac{1}{4}\,\frac{(1-y)^2}{1+y^2}$	0	$\frac{1}{4}\,\frac{(1+y)^2}{1+y^2}$

The essential fact contained in the above expressions is that the quasi singlet and the quasi triplet are populated unequally. It will now be shown that they have different lifetimes and can therefore be separated by a measurement of the time distribution of the positronium annihilations.

Positronium in the singlet state in the ground space state annihilates principally into two quanta at a rate of 8×10^9/sec. In the triplet state, it annihilates principally into three quanta at the rate of 7×10^6/sec. In the presence of a magnetic field, the $M = \pm 1$ triplet states remain pure triplets and continue to annihilate at the slow rate. The $M = 0$ singlet and triplet, however, are mixed. Thus there is a greatly increased annihilation rate in the quasi triplet state, while the quasi singlet annihilation rate is only slightly decreased. The rates, calculated from the quasi triplet and the quasi singlet wave functions are:

Quasi Singlet Rate: $$\Gamma_{00} = \frac{1}{1+y^2}\left\{8\text{x}10^9 + 7\text{x}10^6\, y^2\right\}$$

Quasi Triplet Rate: $$\Gamma_{10} = \frac{1}{1+y^2}\left\{7\text{x}10^6 + 8\text{x}10^9\, y^2\right\}$$

At the magnetic field strength used for the measurements described in this paper, $y \approx \frac{1}{4}$, both the quasi triplet and the quasi singlet decayed principally by two quantum emission. The effect of the different detection efficiency of the apparatus for the two and three quanta annihilation modes has therefore been neglected. Although the polarization dependent population difference increases with magnetic field, the lifetimes of the quasi singlet and the quasi triplet approach each other so that the observable effect decreases. In practice the finite resolving time of the electronics is also a factor which limits the useable field. In the present experiment, the resolving time curve was approximately Gaussian in shape and had a full width at half maximum of about 1.5×10^{-9} seconds. The optimum magnetic field was determined experimentally by observing the effect at various field strengths. A value of 17.5 KG was chosen.

When a high energy positron is degraded to rest, the range straggling is considerable. Furthermore, in many cases of beta decay, the source emits a continuous spectrum of particles. In order to stop a sufficient fraction of the positrons emitted by the source for the method to be efficient, it is necessary that the positronium forming medium be thick and dense. For reasons of experimental convenience, the material chosen as a stopper was plastic scintillator.*

When positronium is formed in plastic, the theory described previously, valid in free space, is not an adequate description of the annihilation process. The time distribution on the annihilations consists of a long component with a mean life of about 2 x 10^{-9} seconds and a short component with a mean life too short to be resolved with the apparatus used here. Recently it has been shown (10,11) that the short component consists of at least two separate components decaying with mean lives less than 10^{-9} seconds. Furthermore, very little three quantum annihilation is observed. If the long component is assumed to be due to triplet positronium states which decay rapidly by interactions with electrons in the plastic, the intensity ratio between the short and the long component is not in agreement with the free space theory. It is usually assumed that this is because some of the positrons annihilate quickly without forming positronium. Because the process of positronium annihilation in plastic is not fully understood at present, it is not considered a reliable procedure to make an absolute measurement of polarization from the observed intensity ratios in the annihilation time distribution.

* 97.5% polystyrene, 2.5% p-terphenyl, .03% tetraphenylbutadiene, .01% zinc sterate

10. Spirn, Brandt, Present, and Schwarzschild, Bull. Amer. Phys. Soc. 9, 394 (1964)

11. A. W. Sunyar, Bull. Amer. Phys. Soc. 9, 394 (1964)

The apparatus described here was calibrated with positrons from the decay of Cu^{64} at an energy of about 0.4 MeV. The depolarization measurements which will be described will refer to the depolarization between a high energy and 0.4 MeV.

III. EXPERIMENTAL ARRANGEMENTS AND RESULTS

A. The apparatus used in these experiments varied, depending on the energy of the positron being measured. In all cases the analyzing magnet consisted of a five inch diameter, eight inch long iron clad solenoid. The positron beam was brought into the solenoid along the axis through one end. It was degraded inside the uniform field region, and came to rest in plastic scintillator at the center. The other end of the solenoid was used for access of the light pipes.

It was found that the inhomogeneous magnetic field at the entrance of the solenoid had the property of focussing positrons entering at large angles off-axis to the center of the solenoid. For those positrons entering off-axis at a large angle to the fringe field, the trajectories are such that at the center of the solenoid, the path is a tight spiral with the momentum largely transverse to the axis.* Because of the conservation of $\vec{\sigma} \cdot \vec{p}$ in the presence of a magnetic field, such positrons are not polarized along the magnetic field direction at the degrader. With a 0.4 MeV positron beam entering the solenoid 20° off-axis, and intersecting the fringe field at a much larger angle, the depolarization was found to be 85±15% with respect to the on-axis value. For this reason, the beam was limited to a maximum angle at entrance of 2° in the experiments discussed in the following sections, with the exception of one run which is treated separately.

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* This was pointed out by Dr. N. Cabibbo - For a discussion of trajectories in nonuniform magnetic fields, see Northrop, T. G., The Adiabatic Motion of Charged Particles, Interscience, New York 1963

For the experiments at 0.4 and 2.7 MeV, the arrangement of Fig. 1 was used. Positrons from a radioactive source attached to a 5 mg/cm^2 mylar window at the end of an evacuated collimating system were brought to rest in counter t_o . The collimating slits were 0.25" diameter holes in 0.625" copper discs. In the experiments at 0.4 MeV, the slit thickness was varied between 0.015" and 0.0625" to measure the effect of slit scattering. There was no observable change in the polarization.

The electronic system was a conventional fast-slow arrangement in which coincidences between slow pulses from the scintillators gated the output of a fast delay time analyzer. The slow pulses were passed through single channel analyzers in which both maximum and minimum pulse height levels were set. The delay times were measured with a converter from delay time to pulse height. The pulse height analysis was performed by a multichannel analyzer. The time drift in the overall system was less than 2 x 10^{-10} seconds/day and had no observable effect on the polarization measurement. The multichannel analyzer memory was divided into two parts which were addressed depending on the magnetic field direction in the solenoid. The solenoid field direction was changed automatically at ten minute intervals in order to reduce the effects of instrumental instabilities. Whenever there were two or more pulses in the t_o scintillator within two microseconds, the events for the previous and following five microseconds were discarded. This was done to prevent pile-up and to reduce chance rate.

In the experiments carried out at 0.4 MeV, Cu^{64} was used as a source of polarized positrons. The source was a 0.25" diameter 2.8 mg/cm^2 thick disk of natural abundance copper which had been irradiated for 20 hours at a thermal neutron flux of 10^{13}n/cm^2 sec. This source had a disintegration rate into positrons of 3.3×10^7/sec. at the beginning of the experiment. It was attached to the inside of the mylar window of the vacuum system with a small piece of adhesive tape. As in all the experiments to be described here, the single channel analyzer on the annihilation gamma counter was set to accept the upper 20% of the pulse height distribution. The positronium forming counter, t_o, was one inch thick during these measurements. The single channel analyzer on this counter accepted positrons which deposited between 375 and 475 KeV in the scintillator.

The time distribution of the acceptable coincidences is shown in Fig. 2. Long delay times correspond to small multichannel analyzer addresses. The polarization dependent effect is defined by the ratio

$$\epsilon = \frac{N(\tau \uparrow) - N(\tau \downarrow)}{N(\tau \uparrow) + N(\tau \downarrow)}$$

of the counting rate N. The arrows denote magnetic field directions. ϵ depends on the time τ between the positron stop and the detection of an annihilation gamma ray. This ratio at a magnetic field of 17500 gauss is shown in Fig. 3a, where the time scale is the same as that of the delay spectrum of Fig. 2. The curve has been normalized so that the average effect taken over all times is zero. The general features of the curve are: 1) the effect approaching zero for large times; this contribution is attributed to the magnetic field independent $M \pm 1$ triplet states, 2) the large negative going effect at intermediate time delays; this is due to the contribution of the quasi triplet with an intermediate lifetime, and 3) the positive effect at short times; this is due to the quasi singlet.

For the positrons in the 375 - 475 KeV energy interval, the average value of the polarization is $< \frac{v}{c} > = 0.83$. This is taken to be the polarization of the beam incident on the degrader in the experiment described here. To investigate the effect of scattering in the radioactive source, a similar experiment was performed with a 23 mg/cm^2 thick copper source. The polarization effect was 0.85 of that observed with a 2.8 mg/cm^2 source. At lower magnetic fields, the shape of the polarization dependent signal is different. Fig. 3b shows the effect at a magnetic field of 5000 gauss. At such a field, the quasi triplet lifetime is not appreciably shortened in comparison with the $M = \pm 1$ triplet state lifetime in plastic scintillator. In this case, the polarization dependent effect approaches a constant value for times long enough that there is no contribution from the quasi singlet; this value is:

$$\epsilon = \frac{2}{3} \frac{y}{1+y^2} \cdot P$$

In this expression, P is the polarization of the incident beam. At 5000 gauss, $\epsilon = .046\ P$. The motivation in doing a low field experiment is that the finite time resolution of the electronics is no longer a factor in determining the effect. In order that the statistical accuracy of the experiment be satisfactory, a shorter, more efficient, collimating system was used. Under these conditions, the magnet depolarized the incident beam by about 15%. Taking this into account, the expected limiting effect with Cu^{64} should be 3.2%. The observed effect is only 2.2% indicating that there is some depolarization in slowing down, or in the capture process; or that some not understood property of positronium in plastic is important. The experiments described here do not permit a differentiation to be made between these possibilities.

Measurements were made at higher energy with positrons from the decay of Ga^{66} . A 180 mg/cm^2 foil of natural abundance zinc was bombarded with 30 micro coulomb hours of 13 MeV protons. The gallium was extracted with ether. Considerable material was extracted with the gallium, and the resulting source had a thickness of roughly 50 mg/cm^2. For this experiment, the single channel analyzer on the positron stopping counter was set to accept positrons depositing between 2.5 and 3 MeV in the scintillator. The remaining apparatus was identical to the Cu^{64} apparatus. There was a 10% prompt coincidence background from Compton scattering in the stopping counter and from coincidences from the source itself. This background was field independent and did not affect the normalization of the polarization signal. The results, with the background not subtracted, are shown in Fig. 3c. The quasi triplet effect, which is not affected by a prompt background, is seen to be considerabley attenuated in comparison to the Cu^{64} result. The polarization of the incident beam in this case is assumed to be 100%. The polarization of positrons from Ga^{66} has been measured by annihilation in flight by Deutsch et al. (12) and was shown to be consistent with $< \frac{v}{c} > = 1$.

B. <u>Accelerated Positrons</u>

To obtain a beam of high energy polarized positrons, low energy polarized positrons from a Cu^{64} source were accelerated in the linear accelerator at Livermore (13). A 23 mg/cm^2, 3/8" diameter natural abundance copper disk was bombarded for 24 hours at a thermal neutron flux of 10^{14}n/cm^2-sec. This disk was attached to a 1/4" diameter beryllium rod and was placed at the entrance to the first 5' section of

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12. Deutsch, Gittelman, Bauer, Grodzins, and Sunyar, Phys. Rev. 107, 1733 (1957)
13. Austin, and Fultz, Rev. Sci. Inst. 30, 284 (1959)

disk loaded waveguide in the accelerator. An axial time independent magnetic field of approximately 100 gauss at the entrance, and varying strengths along the accelerator, was used to focus the positrons. A second 5' section of waveguide was energized when runs were made at 24 MeV. At the exit of the accelerator, the beam was analyzed with a pair of 40° bending magnets and a pair of quadrupoles. Two sets of aluminum slits were adjusted to give a momentum uncertainty at the exit of the analyzing system of less than ±2%. The beam spot at the entrance to the polarization analyzing magnet was roughly 1/2" in diameter.

In an electron linear accelerator, there is no phase oscillation because the particles move at nearly the speed of light. Consequently, the energy of an accelerated particle is proportional to $\sin\phi$, where ϕ is the phase angle of the radio frequency at the time the particle enters the accelerator.

Since the radioactive source is emitting at all times, the effective phase acceptance of the accelerator is determined by the magnetic momentum analyzing system at the exit. The acceptance is:

$$\Delta\phi = \left(\sin^{-1}\frac{p_{max}}{A} - \sin^{-1}\frac{p_{min}}{A}\right)_{+} + \left(\sin^{-1}\frac{p_{min}}{A} - \sin^{-1}\frac{p_{max}}{A}\right)_{-}$$

In this expression, A is proportional to the electric field strength in the accelerator, p_{max} and p_{min} are the momentum acceptance limits on the exit magnetic analyzing system, and the $+$ and $-$ refer to the solution of the equation on the rising and falling edge of the accelerating R F wave. There is a maximum in $\Delta\phi$ when the accelerating voltage is such that particles entering at $\phi = 90^\circ$ exit with the maximum momentum accepted by the analyzing system. Such behavior was observed with positrons accelerated from the source. During the runs, the R F power in the accelerator was tuned to satisfy this condition. It should be noted that the above analysis is only approximately correct because the first foot of the waveguide had a phase velocity which was less than c .

The momentum acceptance of the accelerator as a function of positron momentum at the entrance has not been investigated. For the purpose of calculating the polarization of the exit beam, a value of $< \frac{v}{c} > = .74$ which is an average over the beta spectrum of Cu^{64} has been assumed.

To test the effects of scattering, an umbrella shaped piece of lucite was placed over the source so that only positrons scattered from the sides of the waveguide near the source could be accelerated. Under these conditions the accelerated beam was only 2% of the beam without the umbrella. Furthermore, with the source removed, no positrons were detected. Experiments with polarized electrons accelerated by the method described here are impractical because a large electron beam is observed with the source removed.

To account for the source scattering depolarization observed from a 23 mg/cm^2 copper disk, a 15% depolarization has been assumed. Baring depolarization from some other source, the polarization of the linac exit beam has been assumed to be $P = 0.74 \times 0.85 = 0.65$, independent of the energy of the beam.

Depolarization in the acceleration process has been calculated by Drs. McMillan (14), and Panofsky (15) who have shown it to be negligible. These calculations, however, neglect the effects of the higher order space harmonics of the accelerating field.

The apparatus used to analyze the 12 MeV beam is shown in Fig. 4. The vacuum system of the accelerator, not shown, terminated with a

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14. E. M. McMillan, private communication
15. W. K. H. Panofsky, SLAC-TN-63-97

68 mg/cm^2 aluminum window 2" ahead of counter S5. Positrons stopping in the 2" diameter 2" long scintillator contained in the S8 anticoincidence cup were identified by a S5-S6-S7-$\overline{\text{S8}}$ coincidence. The stopping scintillator was covered with aluminum foil. The light from this scintillator was not used. Two independent delay time to pulse height converters were used with two pulse height analyzers. The signal from S5 was used as a common zero time for both channels. Coincidences between the gamma ray detectors were not required. A positron stop in coincidence with an energy discriminated gamma ray in one of the gamma counters gated the output of the delay time to pulse height converter into the analyzer corresponding to the gamma counter. In order to improve the time resolution, a pulse height condition was set on S5 which eliminated the high pulse height tail from fluctuations.

In order to eliminate chance rate, only events in which one particle passed through counter S6 in the 0.5 microsecond accelerator pulse were accepted. Under normal conditions, the accelerator was operated at a rate of 360 pulses/second, and the acceptable beam rate averaged 125/second. About 20% of the events were rejected because of the more than one particle per pulse condition.

About 10 percent of the events were due to bremsstrahlung being detected in the gamma ray counters. These events were prompt coincidences and interfered only with the quasi singlet population measurement which is not used in the polarization determination. The results of the 12 MeV measurement, with the background not subtracted, are shown in Fig. 3d.

A similar measurement was made at 24 MeV. The apparatus was the same as that of the 12 MeV run except for the addition of 1.5 inches of carbon ($\rho = 1.7$) directly ahead of S7 inside the analyzing magnet.

Two sections of the linear accelerator were energized to produce a 24 MeV beam. The prompt coincidence background due to bremsstrahlung was more severe, amounting to about 25% of the counting rate. The results, without background subtraction, are show in Fig. 3e. Runs were also taken with 1.75 inches beryllium degrader in place of the carbon with essentially identical results. Another run, taken with a 23 mg/cm^2 beryllium foil covering the copper source, gave a similar result.

In order to check for false effects, an unpolarized positron beam was made by bombarding a copper target between the first two linear accelerator sections with electrons accelerated from a thermionic source. Positrons produced from the bremsstrahlung-pair production sequence were accelerated in the second and third sections of the accelerator by changing the phase of the RF 180° after the copper target. In this case the final energy was 24 MeV and the degrader was 1.75 inches of beryllium. The results are shown in Fig. 3f.

IV SUMMARY OF RESULTS

In comparing results from experiments with different energy positron beams, the presence of varying amounts of prompt coincidence background makes the quasi singlet population ratio for the two analyzing magnetic field directions unsuitable for polarization comparison. The quasi triplet population ratio is not affected by this background. For this reason, the polarization is based on the data in the time interval from analyzer address 36 to 46. In each experiment, the normalization of the time dependent coincidences was such that there were the same number of events for each magnetic field direction. The asymmetry with analyzing field of the prompt coincidence background was in each case measured, and in all cases the effect on the polarization measurement was such that the false effect generated by such an asymmetry was less than 1%. Table 1 shows a summary of the data. In the column under depolarization, what is shown is the depolarization between the incident energy and 0.4 MeV where the analyzer was calibrated.

V. DISCUSSION OF RESULTS

The starting point for the explanation of these results is the expression for the motion of the expectation value of the spin of a spin $\frac{1}{2}$ particle acted on by electric and magnetic fields. Denoting θ as the angle between the expectation value of the spin direction of the particle in its *rest frame* and its velocity in the laboratory system, the rate of change of θ is:

$$\frac{d\theta}{dt} = \frac{e}{2m} \left[(\vec{E} \cdot \vec{n}) \frac{(g-2) - \frac{g}{\gamma^2}}{\beta} + (g-2) \vec{\ell} \cdot \vec{H} \times \vec{n} \right]$$

In this expression, all quantities are measured in the laboratory system excepting θ. $\vec{n}$ is a unit vector perpendicular to the velocity of the particle in the laboratory, and $\vec{\ell}$ is a unit vector parallel to the velocity.*

At low velocities, the effect of an electric field is to alter the trajectory of a particle without changing the rest system angle of the spin with respect to a fixed direction in the laboratory. At high energies, the effect of the electric field is the same as that of the magnetic field at all energies, and is that of moving the spin along with the momentum. It has been assumed that the total amount of trajectory change has been sufficiently small that (g-2) effects are small. Since the fields acting on a positron while it is being degraded are primarily electric, it is clear from the above that a positron stopped from a low initial energy will

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* A discussion of this equation is given by Hagedorn, R. *Relativistic Kinematics*, W. A. Benjamin, 1963 p. 124-161

retain its component of initial polarization along its orginal momentum direction, that is, the direction of the magnetic field in the polarization analyzer.

When a high energy positron is degraded, the spin will follow the momentum until the positron is degraded to a low energy, at which point the spin no longer moves. The transition between these two modes of behavior occurs at an energy of about 1 MeV. Because of this behavior of the spin, the depolarization in the degrading process is sensitive to the geometry of the degrader and collimator. In the experiments described here, the beam of particles was collimated at high energy before entering the degrader, after which there was no additional collimation. Because scattering greatly disperses the positron beam by the time the transition energy region is reached, the spins are no longer parallel to their initial directions. Since no further movement of the spins occurs in the remainder of the degrader, the polarization observed when the positrons stop is reduced to the extent that the beam has been dispersed by the time the transition energy is reached. A calculation of the depolarization of such a beam has been carried out by Bouchiat and Levy-Leblond (16). The results presented here are in rough agreement with this calculation. Depolarization calculations have also been made by Iddings et al. (17)

16. C. Bouchiat and J. M. Lévy-Leblond, to be published in Il Nuovo Cimento
17. Iddings, Shaw, and Tsai, to be published in The Physical Review

TABLE I

Initial Energy	Initial Polarization	Observed Effect	Depolarization
0.375-0.475 MeV	0.83	-6.7 ± .4%	0 (Normalization)
0.5 -3.0 MeV	1.0	-4.0 ± .4%	50 ± 5%
12 MeV	0.65	-1.1 ± .6%	79 ± 12%
24 MeV	0.65	-1.3 ± .7%	75 ± 14%

In principle, by degrading the positron beam to 1 MeV and then collimating before the final degrading, it should be possible to increase the final polarization. Because of the depolarization caused by the analyzing magnet, the collimation would have to be very narrow. Furthermore, because of the narrow range interval which would be covered, few positrons would be stopped. The method would therefore be very inefficient. For these reasons, it does not at present seem practical to apply this method of polarization detection to high energy positrons.

We wish to thank Prof. E. Segrè for advice and encouragement, and Prof. H. Bethe for a discussion of the depolarization process. We thank Dr. S. Fultz and the staff of the Livermore accelerator for their assistance. The chemical separations were performed by Mr. D. Allaway. The analyzing magnet was designed by Mr. R. Wollgast.

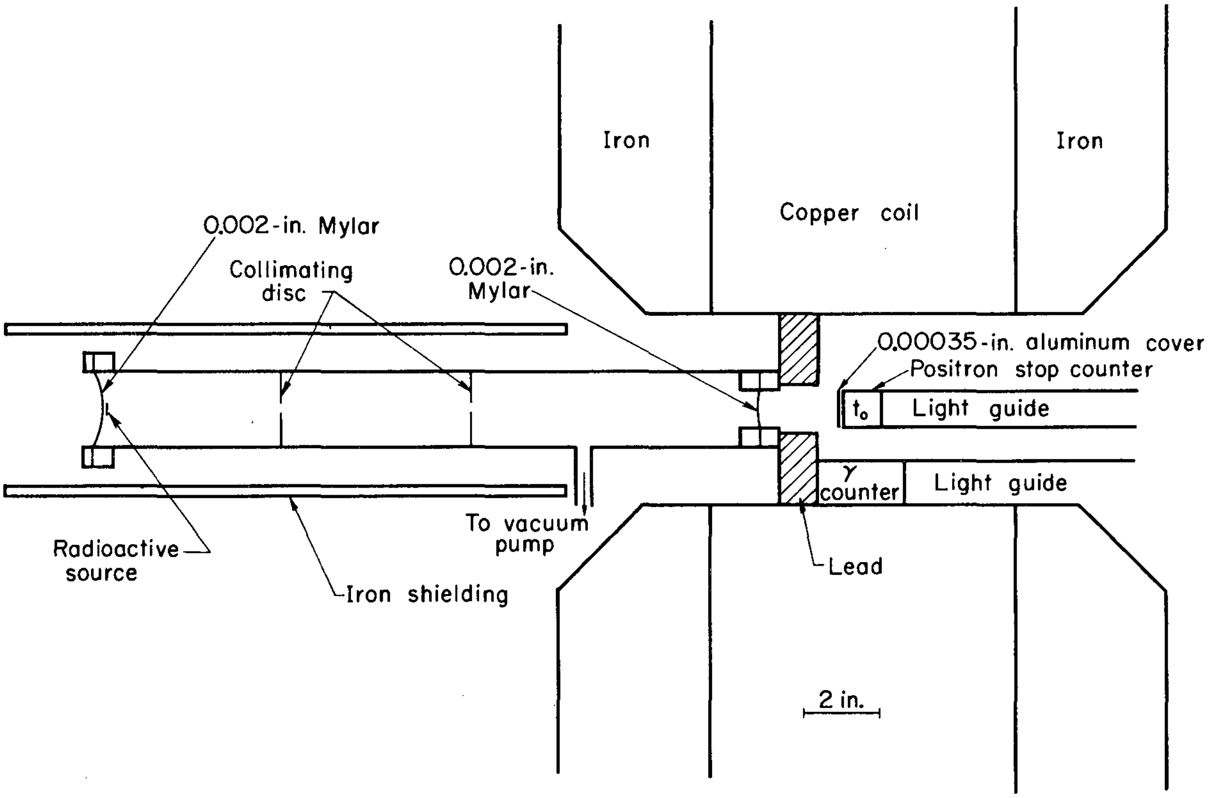
FIGURE CAPTIONS

1. Apparatus used for polarization measurements at 0.4 MeV and 2.7 MeV.

2. Time distribution of positron annihilations in plastic scintillator. Long times correspond to small multichannel analyzer addresses.

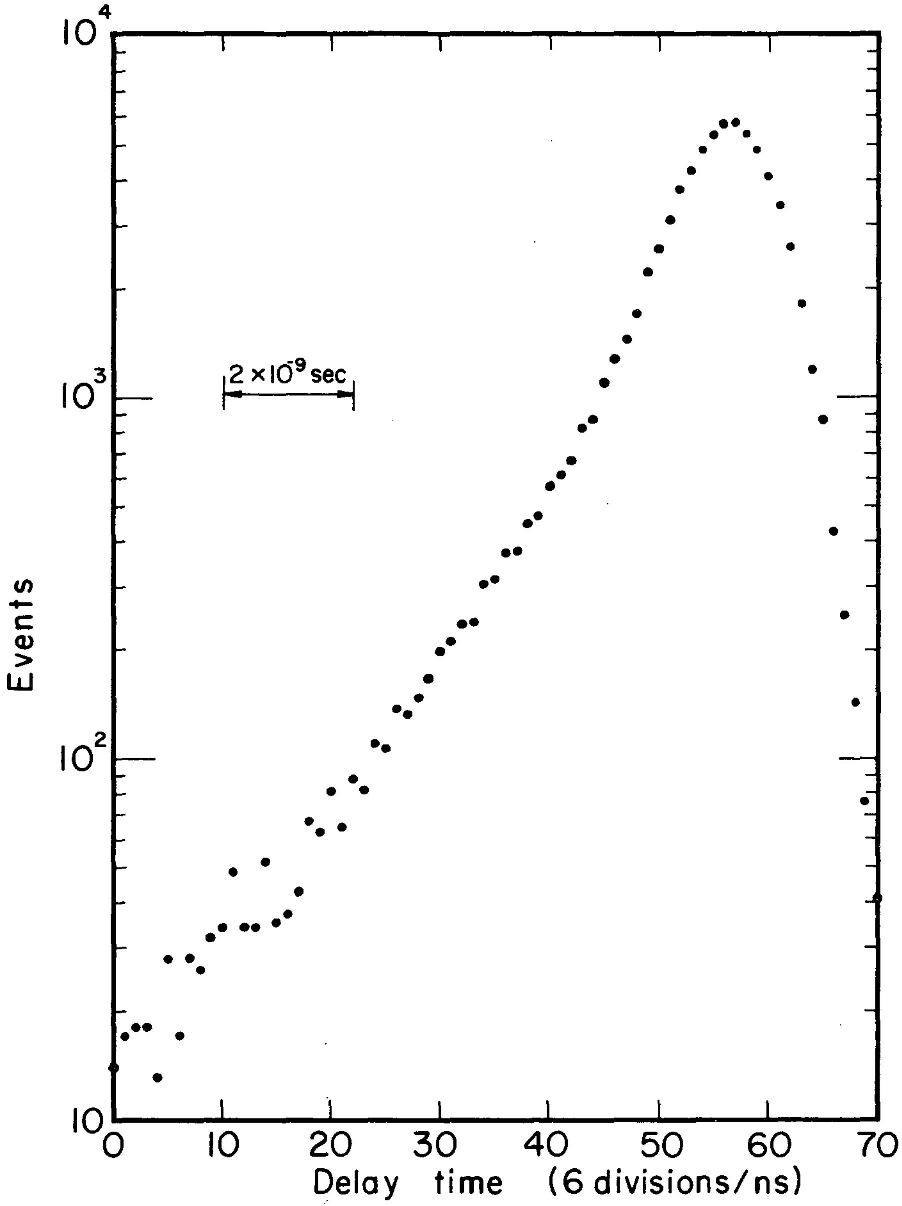
3. Polarization dependent signal from: (a) Cu^{64}, 0.4 MeV, 17.5 KG (b) Cu^{64}, 0.4 MeV, 5KG (c) Ga^{66}, 2.7 MeV, 17.5 KG (d) 12 MeV accelerated positrons from Cu^{64}, 17.5 KG (e) 24 MeV accelerated positrons from Cu^{64}, 17.5 KG, and (f) unpolarized 24 MeV positrons, 17.5 KG.

4. Apparatus used for polarization measurements at 12 and 24 MeV.



MUB-3143

Fig. 1



MUB-3142

Fig. 2

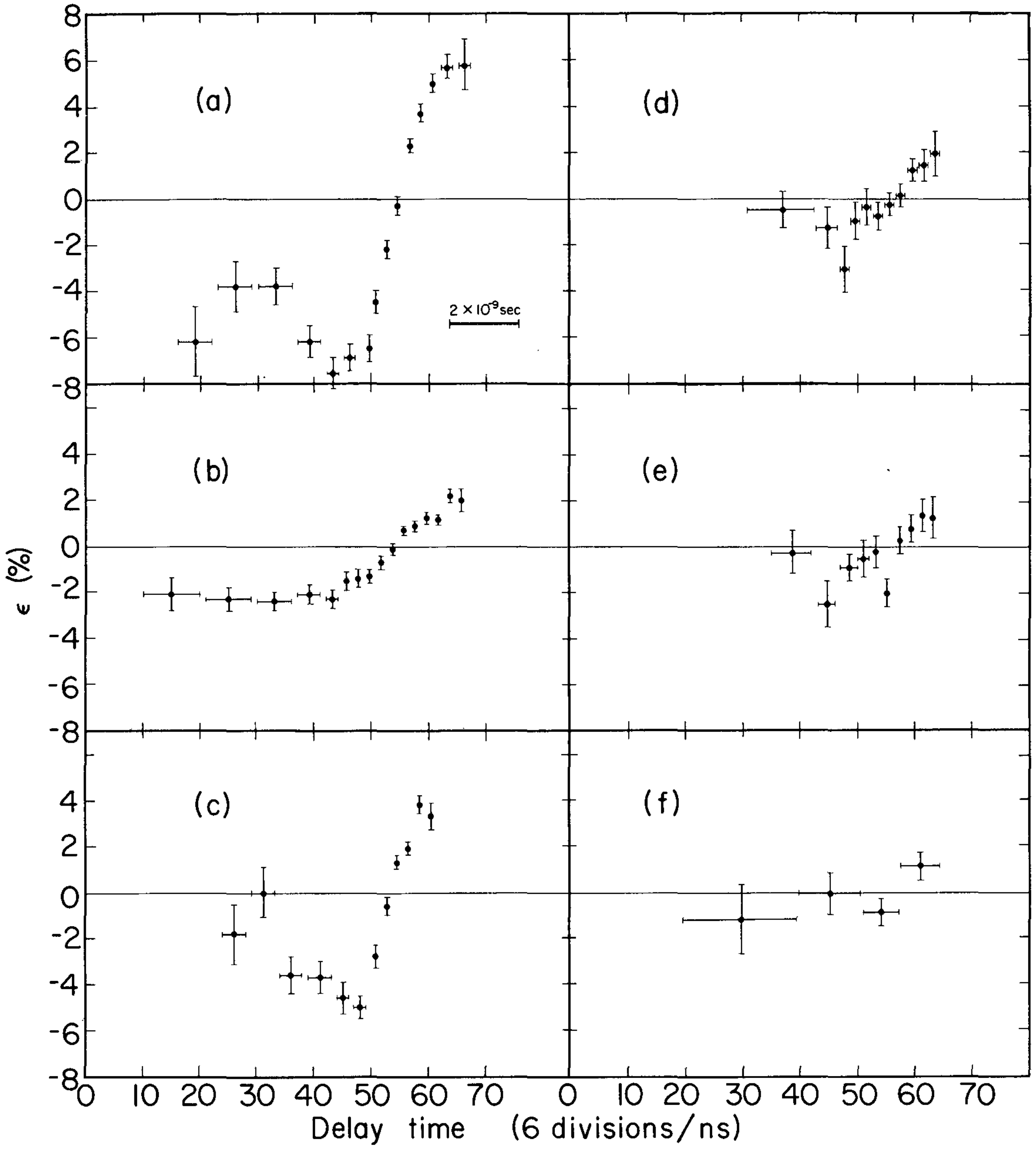
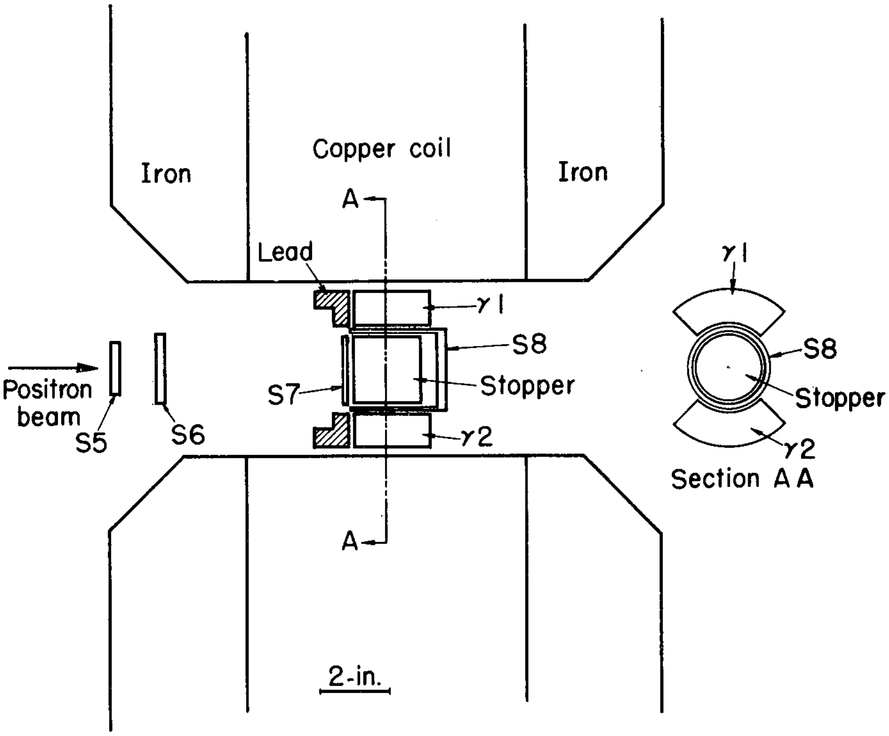

(a)
(b)
(c)
(d)
(e)
(f)
2 × 10⁻⁹sec
ε (%)
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
70
Delay time (6 divisions/ns)
MUB-3144

Fig. 3



MU-32621

Fig. 4