*Research was supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

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MEASUREMENTS OF MUON DISAPPEARANCE RATES vs TIME IN C, Mg, Al, Si, AND P[†]

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At the 1960 Rochester Conference we reported[1] some preliminary evidence for the observation of a hyperfine structure (i.e., spin dependence) effect in the capture of muons by ${}_{13}\text{Al}^{27}$ and ${}_{15}\text{P}^{31}$. This effect[2] consists in a (negative) curvature[3] K of the plot of $f(t)$, the logarithm of the electron rate from these targets, vs time,

$$K=K(0)=f''(1+f'^2)^{-3/2} \text{ at } t=0, \tag{1}$$

and depends on the physical rates as follows:

$$K=K(\Delta\Lambda,R)=-2^{-3/2}n_+(\Delta\Lambda/\bar{\Lambda})(R-n_-\Delta\Lambda)/\bar{\Lambda}, \tag{2}$$

where $n_\pm$ are the statistical weights of the hyperfine states $F_\pm=I\pm\frac{1}{2}$, $\bar{\Lambda}=n_+\Lambda_+ + n_-\Lambda_-$ the mean disappearance rate, $\Delta\Lambda=\Lambda_- - \Lambda_+$, and R is the conversion rate from F_+ to F_- (assuming a positive nuclear magnetic moment).[4]

We have now repeated these "curvature" measurements under greatly improved conditions, and have found that, to within experimental error, $K=0$ for Al and Mg. We used the experimental setup schematically indicated in Fig. 1. The most essential improvements were the following ones:

(a) Comparison of the Al target ($I=\frac{5}{2}$) data with Mg data (mostly $I=0$) obtained under essentially identical conditions. In the past, C reference

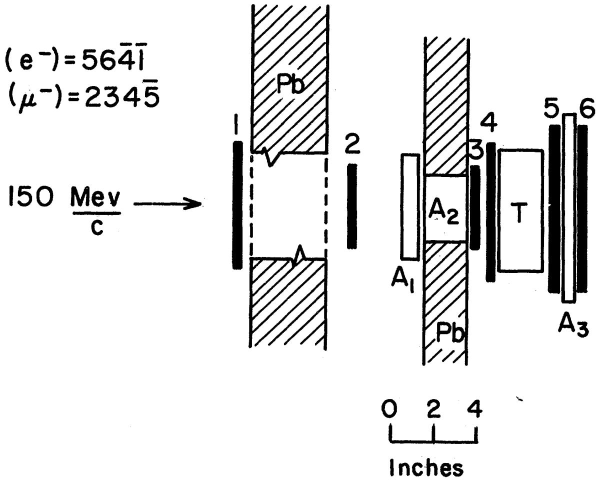

FIG. 1. Experimental setup. 1, 2, 3, 4, 5, and 6, square scintillation counters; $A_1=\frac{3}{4}$-in. Cu moderator, $A_2=$ 2-in. graphite moderator, $A_3=\frac{1}{2}$-in. polythene absorber. Pb = Pb collimators. $(\bar{1}456)$ = electron coincidence, $(234\bar{5})$ = muon coincidence.

Table I. Experimental results on curvature in Mg and Al.

Target	$K \times 10^3$	Accidental background (% at $t = 0$)	Carbon background (% at $t = 0$)
Mg	$+(1.1 \pm 1.0)$	0.209 ± 0.002	0.09 ± 0.38
Al	$+(2.4 \pm 1.7)$[a]	0.295 ± 0.004	0.03 ± 0.29

[a] To be compared with the value $K = -(4.4 \pm 1.0) \times 10^{-3}$ given in reference 1.

targets had been used to get "uncurved" data; however, C targets can show no background from muon decays in carbon—an essentially inevitable phenomenon with all other targets. This carbon background could simulate negative curvature through reduced reliability in fitting the time distribution.

(b) Improved time range of observation. To get a better evaluation of the flat, accidental background, an interval of 9 μsec was observed at $t < 0$ (i.e., before the arrival of each muon). A longer (16-μsec) time range at $t > 0$ was made available for observation in order to make the data statistically more valuable for separation (by least-squares program) into flat accidental background and exponential carbon background. Accidental backgrounds from $t < 0$ data and from fit to $t > 0$ data were required to match.

(c) Improvements in "digitron,"[5,6] the clock used to measure the distribution of μ-e time intervals. These improvements, to be described in detail elsewhere,[6] consisted primarily in replacing the pulsed oscillator with a continuous oscillator and scaler controlled gate combination, and in general using dc coupled transistorized circuits.

(d) Reduction of accidental background, achieved both by providing additional protective circuits in "digitron" and by using a high duty-cycle (~20%) muon beam.[6]

(e) Reduction and direct measurement of carbon background. Directly measured carbon background and carbon background from least-squares fits to $t > 0$ data were required to agree. Reduction was acheived by covering scintillators 4 and 5 with thin (1-mil) Ag foils and not using Scotch tape in addition thereto, as well as by increasing their anticoincidence efficiencies. The short-lived muons stopping in these Ag foils essentially do not contribute electrons to the $t > 0$ range used in data reduction. The direct carbon background measurements were made with an "equivalent" Cu target. The short (Cu) and the long (C) components separate easily. Two layers of Scotch tape (16 mg/cm^2), added on the upstream face of counter 5, could readily be detected in the presence of a 9 g/cm^2 Cu target. This purposely created carbon background could be used to gauge the carbon background present in the actual (Mg and Al) runs.

To make the "curvature" (Al) and the "control" (Mg) runs as closely comparable as possible, the Al target consisted of 5 equally spaced $\frac{1}{4}$-in. thick sheets filling the same volume (6 in. × 6 in. × 2 in.) as the Mg target. Table I summarizes our most reliable data obtained with these targets; to within experimental error, $K = 0$ in both Al and Mg—in contrast to our preliminary evidence for Al. A recent calculation of the conversion rate[7] yields $R(\text{Al}) = 3.2 \times 10^7$ sec^{-1}. With this large value of R, $K(t)$ becomes a rapidly varying (decreasing) function of time.[4] Under these circumstances the "curvature" $\bar{K}$ obtained by fitting the electron time distribution over several mean lives is no longer given by (2) but rather by $\bar{K} = -2^{-3/2} n_+ \times (\Delta\Lambda/R)(\bar{\Lambda}/R)$. With the above value of R and the estimate[2] $\Delta\Lambda/\bar{\Lambda} = 0.17$, one has $\bar{K} \simeq -5 \times 10^{-5}$. This is in agreement with the null result in Table I.

In the course of our search for spin-dependent effects in muon capture, we have obtained rather precise μ lifetimes for C, Mg, Al, Si, and P. These, as well as some quantities derived from them, are summarized in Table II.

Table II. Precise μ^- lifetimes for C, Mg, Al, Si, and P.

Target	Lifetime[a] (μsec)	Capture rate[b] $\Lambda^{\text{cap}} \times 10^{-5}$ (sec^{-1})	$\Lambda^{\text{cap}}/\langle\rho\rangle$[c]
C	2.041 ± 0.005	0.361 ± 0.01	17.8 ± 0.5
Mg	1.071 ± 0.002	4.80 ± 0.02	19.4 ± 0.1
Al	0.864 ± 0.002	6.62 ± 0.03	21.4 ± 0.1
Si	0.767 ± 0.002	8.50 ± 0.03	19.9 ± 0.1
P	0.635 ± 0.002	11.21 ± 0.05	21.0 ± 0.1

[a] Statistical error computed from least-squares fit to data.

[b] Computed using the free muon decay rate, $\Lambda_{\text{dec}} = (4.539 \pm 0.005) \times 10^5$ sec^{-1}.

[c] $\langle\rho\rangle$ as defined and given by J. C. Sens, Phys. Rev. 113, 679 (1959).

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[2] J. Bernstein, T. D. Lee, C. N. Yang, and H. Primakoff, Phys. Rev. 111, 313 (1958).

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[4] The time dependence of the electron rates can, of course, be characterized over a span of several mean lives by K as defined in (1) if, and only if, K is a slowly varying function of time. This is the case when $R \lesssim \overline{\Lambda}$, an assumption that appeared plausible[3] when these measurements were performed.

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SEARCH FOR HIGH-ENERGY COSMIC GAMMA RAYS*

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This note describes an attempt to detect gamma rays of cosmic origin in the energy region appropriate to π^0 decay. Since π^0 mesons are produced in nucleon-antinucleon annihilation, the existence or nonexistence of a gamma-ray flux from certain portions of the sky bears upon questions such as possible collisions between galaxies and antigalaxies[1] and cosmological models which postulate matter and antimatter creation.[2] New upper limits are set on the creation rate and on the density of interstellar antinucleons.

The existence of high-energy gamma rays in the primary cosmic radiation was first investigated by Schein, Jesse, and Wollan using G-M tubes,[3] by Hulsizer and Rossi using ionization chambers,[4] and by Critchfield, Ney, and Oleksa using cloud chambers.[5] These experiments set an upper limit for the flux of the electron-photon component above about 1 Bev at about 1% of the primary cosmic-ray flux. G-M telescopes were used by Perlow and Kissinger,[6] and more recently by Danielson.[7] All of these experiments suffered the disadvantages of either a high proportion of locally-produced background or an energy sensitivity which did not extend significantly into the 70-Mev region, and none had a directional survey of the sky as its purpose.

A cross section of the balloon-borne detector that was used in the present experiment is shown in Fig. 1. Incoming gamma rays, collimated by

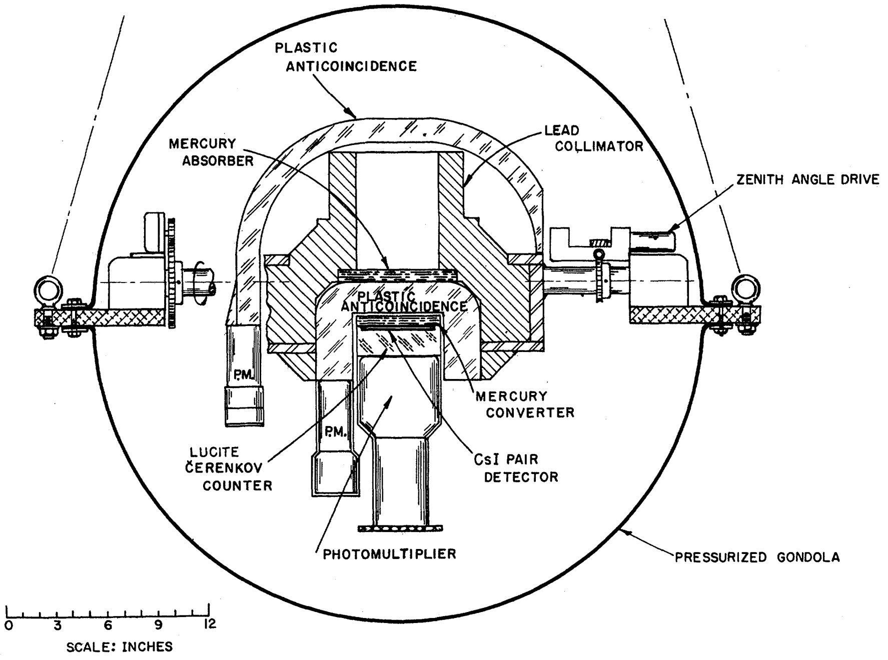

FIG. 1. Cross section of the apparatus. The geometrical figure for this telescope was 1.7 cm^2 sr.