Bringing together our findings, we have shown that the determination of the em structure of the neutron from elastic e-d scattering is highly sensitive to the amount of meson current contributing to the deuteron form factors at $t=0$. It is clear then that to make any definite statements concerning either the value of the C's or the nature of the neutron form factors requires some independent source of information. The electrodisintegration process provides such an independent source. If we make an ad hoc comparison with the results of DeVries et al.,[1] we conclude (1) that meson currents do not contribute to magnetic scattering [i.e., $B(t)$ in (8)]; however, the 2% effect speculated by Adler and Drell is not excluded; and (2) that there is an appreciable meson-current contribution (at least 5%) to both the charge and quadrupole form factors of the deuteron. Although (1) is consistent with present ideas on the order of magnitude of the meson current, (2) represents an appreciable departure. To investigate further this latter possiblity, one needs a description of the inelastic process which adequately takes into account meson current effects.[14] This to our knowledge has not as yet been accomplished.

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PRECISE MEASUREMENT OF THE K^+/K^- AND π^+/π^- LIFETIME RATIOS*

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It is well known that if the weak-interaction Hamiltonian is invariant under the CPT operation,[1,2] then to first order in the weak interaction the total decay rates for particle and antiparticle are equal. The equality of the lifetime of particle and antiparticle is known to 0.1% for muons[3] and to 0.7% for pions.[4,5] The present experiment was designed in order to measure the ratio $\tau(K^+)/\tau(K^-)$ which was previously known very poorly.[6,7]

We have chosen to measure the number of K mesons in a well collimated beam that do not decay over a distance ranging from one to three lifetimes (in the laboratory). If $R = N/N_0$ is the attenuation of the beam (where N_0 is the initial number of K mesons and N the number of K's surviving at a distance l), then[8]

$$(p_+\tau_+)/(p_-\tau_-) = (\ln R_-)/(\ln R_+).$$

We have used the electrostatically separated[9] K beam of the Brookhaven alternating-gradient synchrotron as shown in Fig. 1(a). The

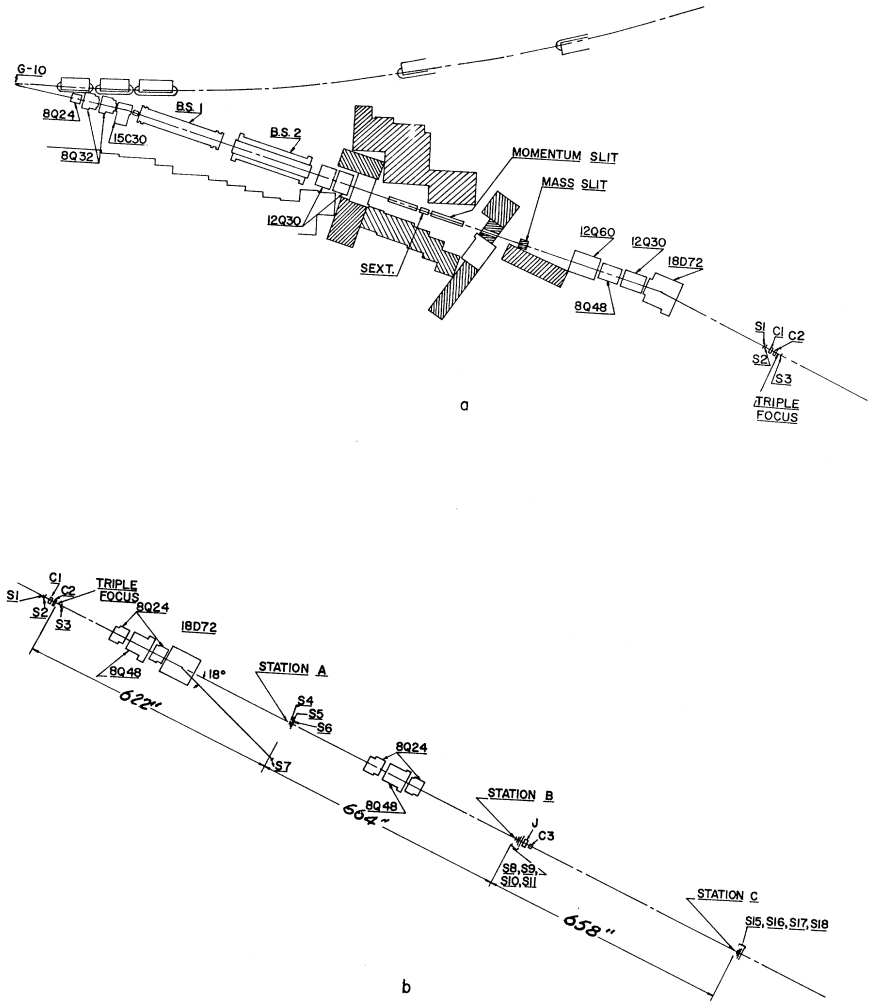

FIG. 1. (a) Separated-beam layout from G-10 to triple focus. (b) The secondary beam.

K mesons were defined at the triple focus by means of two differential Cherenkov counters with 1/2-in. liquid radiators and a 0.5-in. diameter defining counter $S3$. The over-all rejection of the system against pions was better than 10^{-5}. Typical fluxes of 500 K^- mesons/pulse[10] at 1.6 BeV/c were obtained, with a ratio of $K^-/(\pi^- + \mu^-) \approx 0.2$. The K mesons so defined were transported as shown in Fig. 1(b) with two identical 8-in. quadrupole triplets over a distance of 2000 in. Scintillation counters could be inserted at a position 620 in. ($S4$, $S5$, $S6$), 1290 in. ($S8$, $S9$, $S10$), or 1950 in. ($S16$, $S17$, $S18$) downstream from $S3$. The three counters at each station were of progressively larger diameters ranging from 1.5 to 2.5 in. at stations A and B and from 3 to 5 in. at station C. A continuous vacuum pipe was always inserted between $S3$ and the appropriate downstream station.

Measurements were performed at 1.6 and 2.0 BeV/c, the momentum resolution being $\pm 0.75\,\%$. Before and after each alteration of the beam polarity the momentum was measured by use of a bending magnet and counter $S7$ ($\frac{1}{8}$ in. wide). Our relative momentum measurements were accurate to $0.1\,\%$, and during a normal run the bender was turned off.

The material in the beam path (counter $S3$, 10 in. of air, and Mylar window) was 0.150 g/cm^2.[11] In order to test its effect we have performed measurements with additional material and thus are able to extrapolate the attenuation to zero absorber. In order to check the geometric efficiency of our beam transport system we measured the attenuation of protons (or antiprotons) before and after every K-lifetime measurement. This attenuation, which we call the "transmission" of our system, extrapolated to zero material, was of the order of 0.996 to 0.998.[12] The accidentals were continuously monitored in a separate delayed-coincidence channel. Finally, our measured momentum values (or lifetime ratios) were corrected for the effect of the earth's field.[13]

Totally 14 alterations of beam polarity were made and 5×10^7 K mesons were counted. First the transmission (from the p or $\bar{p}$ data) was calculated and the K data between each alteration were corrected for it and for the deviations from the nominal momentum. Next all K data of the same polarity, momentum, and counter were combined and a linear least-squares fit was used to extrapolate to zero absorber. The statistical errors were propagated through the least squares analysis and a χ^2 was obtained as a measure of consistency of the data. If $\chi^2/(n-2)>1$, then all calculated errors were multiplied by $[\chi^2/(n-2)]^{1/2}$. Finally a correction was applied for decay products hitting the downstream counters; this is of the order of 0.7% per 1 in. of diameter, but does not affect the lifetime ratio. The final attenuations were treated in two ways:

(A) The positive/negative ratios (τ_+/τ_-) were formed for each momentum and each counter. In Table I we give, in units of 10^{-3}, $(\tau_+/\tau_- -1)$ and its "scaled-up" error for (1) all data, (2) data from which obviously wrong points with very large χ^2 have been eliminated.[14] The effect of the transmission and extrapolation corrections is less than 1/1000 on the lifetime ratios. The ratios from the three counters in the same station are fully correlated and we have therefore formed for each station [for Data (2)] the arithmetic mean of the ratio and of its error. The five numbers so obtained are statistically independent and can be combined (weighted by $1/\sigma_i^2$) to give our best estimate of the lifetime ratio. We find[15]

$$(\tau_+/\tau_- -1) = -0.000\,90 \pm 0.000\,78, \tag{1}$$

with $\chi^2=0.600$ for four degrees of freedom. As an additional check and in order to weigh each point equally[16] we perform the direct average of all 14 ratios of Data (2) given in Table I. We obtain

$$(\tau_+/\tau_- -1) = -0.000\,49 \pm 0.000\,97. \tag{2}$$

(B) Alternatively we use the final attenuations at each station and fit them to a semilog plot in order to find the best value for the lifetime. By combining the data at 1.6 and 2.0 BeV/c, we obtain the results given in Table II. If we form the mean of these data we obtain again

$$(\tau_+/\tau_- -1) = -0.0010 \pm 0.0017. \tag{3}$$

For the absolute lifetime we obtain[17]

$$\tau(K^+) = 12.265 \pm 0.036 \text{ nsec}, \tag{4}$$

which is in slight disagreement with the recent data of Fitch, Quarles, and Wilkins.[18] Our data are consistent with a pure exponential fit to better than 1% at the largest distance.

As a check of our procedures we have also measured in the same beam the lifetime ratio of the π mesons. These data are less accurate than the K data because of the smaller mass and larger lifetime of the pion. Our results

Table I. Summary of the difference from unity of the K^+, K^- lifetime ratio $(\tau_+/\tau_- -1)$ in units of 10^{-3}.

p (BeV/c)	Station	No. of kaons	Station error	Data selection[a]	Ratio in 1st counter	2nd counter	3rd counter	Mean ratio	Corrected mean
1.6	A	7.2×10^6	±1.5	(1)	+0.32 ±2.9	−0.31 ±3.7	−0.28 ±4.6	+0.12 ±3.3	+0.51 ±3.3
				(2)	+0.13 ±3.8	+0.23 ±3.0	+0.01 ±3.0		
1.6	B	10.1×10^6	±1.3	(1)	−0.35 ±2.5	+2.48 ±5.2	−0.64 ±1.4	−0.74 ±2.0	−0.35 ±2.0
				(2)	−0.47 ±2.7	−0.86 ±1.8	−0.88 ±1.4		
2.0	A	7.2×10^6	±1.5	(1)	−2.24 ±1.5	−0.16 ±1.5	−0.31 ±1.5	−0.75 ±1.5	−0.44 ±1.5
				(2)	−1.95 ±1.5	−0.06 ±1.5	−0.22 ±1.5		
2.0	B	21.8×10^6	±0.9	(1)		−1.38 ±1.1	−1.42 ±1.1	−1.81 ±1.2	−1.50 ±1.2
				(2)		−1.77 ±1.1	−1.84 ±1.2		
2.0	C	13.4×10^6	±1.2	(1)	+0.54 ±3.2	+0.69 ±2.2	−2.92 ±2.1	−1.34 ±2.5	−1.03 ±2.5
				(2)	+0.27 ±3.0	−2.18 ±2.1	−2.10 ±2.3		

[a]Selection (1): All data. Selection (2): Selected data.

Table II. Summary of K^+ and K^- fitted lifetimes using the combined data of both momenta, with all corrections applied. The purely statistical error is of the order of ±0.005 nsec.

	$\tau(K^+)$ (nsec)	$\tau(K^-)$ (nsec)	$(\tau_+/\tau_- -1)$ $\times 10^{-3}$
$S4\ S8\ S16$	12.236 ±0.028	12.245 ±0.022	−0.67 ±2.9
$S5\ S9\ S17$	12.273 ±0.020	12.287 ±0.025	−1.16 ±2.6
$S6\ S10\ S18$	12.287 ±0.027	12.302 ±0.031	−1.24 ±3.4

are based on six alterations of polarity, obtained at 1.6 and 1.2 BeV/c. The resulting lifetime ratios for each counter are given in Table III. If, as before, we form the mean at each station and then take the weighted average we obtain

$$[\tau(\pi^+)/\tau(\pi^-)-1]=+0.0040\pm0.0018. \tag{5}$$

If, on the other hand, we form the direct average of the six ratios,[16] we obtain

$$[\tau(\pi^+)/\tau(\pi^-)-1]=+0.0023\pm0.0040. \tag{6}$$

For the average value of the absolute lifetime we obtain[17]

$$\tau(\pi)=26.67\pm0.24 \text{ nsec}, \tag{7}$$

to be compared with results obtained by other investigators.[19]

In conclusion we interpret our results as confirming the equality of the K^+ and K^- total decay rates at the level of 1/1000 and of the π^+ and π^- total decay rates at the level of 5/1000. A detailed report of this work will be published elsewhere.

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Table III. Summary of the differences from unity of the lifetime ratio $(\tau^+/\tau^- -1)$ in units of 10^{-3} for π mesons, including the correction for the earth's field.

p (BeV/c)	Station	Ratio	
1.2	B	($S9$) +3.56 ±1.1	($S10$) +4.73 ±1.1
1.2	C	($S17$) +4.34 ±0.9	($S18$) +6.65 ±0.9
1.6	B	($S9$) −3.48 ±1.9	($S10$) −2.00 ±1.9

*Work supported by the U. S. Atomic Energy Comission.

†During the performance of this experiment these authors held guest appointments at Brookhaven National Laboratory.

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[8]We assume $l_+ = l_-$ and $m_+ = m_-$.

[9]Dr. B. Barrish did much of the original design work on the separated beam and we are indebted to him for many helpful discussions.

[10]At a circulating beam intensity of 5×10^{11} protons/pulse. The size of the beam image is larger than $S3$ so that this number represents only 50 % of the total K-meson flux.

[11]In the 1.6-BeV/c run the total amount of material was 0.242 g/cm^2.

[12]From our transmission measurements we can also set an upper limit for the decay rate of the antiproton as $\Gamma(\bar{p}\text{ decay}) < 2\times10^4\ \text{sec}^{-1}$.

[13]This correction is +0.02 % for positive particles of

1.6 BeV/c and of equal magnitude but opposite sign for negative particles. We have used the measured value of the vertical component of the earth's field at the site of our set-up; this was 0.40 G.

[14]In all cases less than 5% of the total data were discarded.

[15]The errors given in Eqs. (1)-(7) are the propagated statistical errors "scaled up" by $(\chi^2/\text{deg of freedom})^{1/2}$ whenever this quantity was larger than 1.

[16]This method of data reduction makes full use of the "randomizing" of errors in momentum setting.

[17]The error shown in Eqs. (4) and (6) includes our estimate of ±0.2% as a systematic error in the absolute value of the momentum. This was obtained both by a floating-wire measurement as well as by precise mapping of the field; the internal consistency of these results was better than 0.1%. It also includes allowance for a 10% error in our decay product correction, and other smaller systematic errors.

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RELATION BETWEEN THE PION-NUCLEON AND THE ρ-MESON COUPLING CONSTANTS FROM PION SCATTERING LENGTHS*

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The scattering length of a pion on an isospin-bearing target can be computed either by applying the U(2)⊗U(2) current algebra or by assuming ρ dominance in the t channel. Comparing the two approaches, we establish

$$(f_\rho^{\,2}/4\pi) = (G_{\pi NN}^{\,2}/4\pi)(g_V/g_A)^2(m_\rho^{\,2}/2m_N^{\,2}),$$

a relation previously obtained on the basis of current algebra applied to $\rho \to 2\pi$.

Recently, exploiting the U(2)⊗U(2) algebra[1] and the partially conserved axial-vector current (PCAC) hypothesis,[2] Tomozawa[3] and Weinberg[4] have derived a remarkable expression for the scattering length a_T of a pion on any isospin-bearing target (t)

$$a_T = -\left(\frac{G_{\pi NN}^{\,2}}{4\pi}\right)\left(\frac{g_V}{g_A}\right)^2 \frac{m_\pi m_t}{m_\pi + m_t}\left(\frac{1}{m_N^{\,2}}\right)\vec{T}_\pi\cdot\vec{T}_t, \quad (1)$$

where $\vec{T}_\pi$ and $\vec{T}_t$ are the isospins of the pion and the target,

$$\vec{T}_\pi\cdot\vec{T}_t = \tfrac{1}{2}[T(T+1) - T_t(T_t+1) - 2], \quad (2)$$

and g_V and g_A stand for the vector and axial-vector coupling constants in nuclear beta decay. The $\vec{T}_\pi\cdot\vec{T}_t$ dependence as well as the sign of the scattering length (attraction for antiparallel isospins, repulsion for parallel isospins) is just what is expected if low-energy pion scattering is dominated by the exchange of a ρ meson assumed to be coupled universally to the isospin current. Indeed, already in 1960[5,6] it was recognized that the exchange of an isovector, vector meson coupled to the isospin with strength f_ρ leads to a force between the pion and any isospin-bearing object represented by a potential

$$V = (f_\rho^{\,2}/4\pi)\frac{\exp(-m_\rho r)}{r}\vec{T}_\pi\cdot\vec{T}_t, \quad (3)$$

from which we obtain

$$a_T = -2\left(\frac{f_\rho^{\,2}}{4\pi}\right)\left(\frac{m_\pi m_t}{m_\pi + m_t}\right)\frac{1}{m_\rho^{\,2}}\vec{T}_\pi\cdot\vec{T}_t. \quad (4)$$

in Born approximation (i.e., neglecting rescattering corrections). Comparing (1) and (4), we get[7]

$$(f_\rho^{\,2}/4\pi) = (G_{\pi NN}^{\,2}/4\pi)(g_V/g_A)^2(m_\rho^{\,2}/2m_N^{\,2}). \quad (5)$$

It is amusing that Eq. (5) is precisely the coupling-constant relation of Kawarabayashi and Suzuki,[8] who applied current algebra to $\rho \to 2\pi$ (supplemented by the universality hypo-