TABLE I. Summary of data. E_0 is the bremsstrahlung upper limit. The K particles observed at these angles and momenta, were produced by 1000-Mev photons in the reaction $\gamma+p\rightarrow K^+ + \Lambda^0$.

E_0 Mev	P_{lab} Mev/c	θ_{lab}	H_2 target	K counts per 10^{15} Mev	Scattered protons per 10^{15} Mev
1070	520	10°	Full	14.4±1.3	8.0±0.9
1070	520	10°	Empty	4.4±0.8	8.7±1.5
900	520	10°	Full	2.2±0.8	5.1±1.2
1070	428	25°	Full	6.1±0.5	1.6±0.3
1070	428	25°	Empty	0.8±0.3	1.2±0.3
900	428	25°	Full	0.2±0.2	2.1±0.8

A detection efficiency of 5% was estimated for K particles with $\beta=0.7$ and this will be tested experimentally in the future.

An event consisting of a count in the three scintillation counters and a time-of-flight count, but no signal from the Čerenkov counter, is used to trigger an oscilloscope on which are displayed the pulses from the three scintillation counters and the output of the time-of-flight coincidence circuit. These pulses are photographed individually for each event.

Events are analyzed by plotting the correlated pulse heights from two of the counters on log paper as shown in Fig. 1. To calibrate the equipment, several thousand minimum-ionizing particles were counted and the corresponding pulse-height data obtained. From these data the K^+ pulse-height limits, shown as dotted lines in Fig. 1, were predicted. The pulse height in the third counter is correlated in a similar manner, leading to a self-consistent method for identifying the K mesons.

Figure 1 shows a small number of minimum-ionizing particles compared with that shown by Donoho and Walker. This is because the Čerenkov counter combined with the time-of-flight requirement has eliminated all but one per thousand of the fast particles going through the system.

Scattered protons are not as well eliminated, although they are clearly separated at the 10° point where the K pulse heights are lower. If, as we believe, these protons come from the target walls and the air path, they should remain when empty target runs are taken, and this is indeed the case.

The data are summarized in Table I.

In calculating cross sections, the empty-target runs are used as backgrounds rather than below-threshold runs, since we believe the background consists mainly of K particles produced in the target walls and the air path, rather than events produced by pions and protons. Inspection of the pulse-height plots for runs made with full and empty target and low synchrotron energy seem to justify this belief.

The cross sections are $\sigma(28.5°)=(1.72\pm0.26)\times10^{-31}$ cm²/sterad and $\sigma(72°)=(1.80\pm0.20)\times10^{-31}$ cm²/sterad in the c.m. system. They are compared to the other published data[2,3] at 1000 Mev in Fig. 2.

The values of the cross sections of Donoho[2] shown in Fig. 2, are different from those reported by Donoho and Walker.[1] This is because additional data were gathered at 42° and 72° in the c.m. system, and an experimentally determined bremsstrahlung spectrum[4] was used, which is more like a thin-target spectrum than the thick-target spectrum assumed originally by Donoho and Walker.

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† Commonwealth Fund Fellow.

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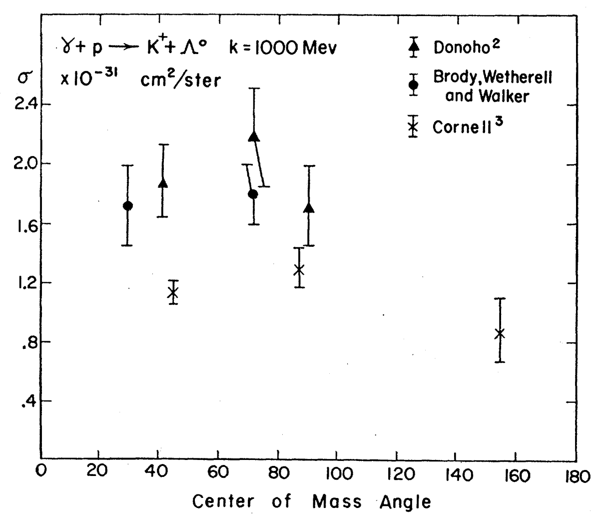

FIG. 2. Angular distribution at 1000 Mev. The Cornell points at 45° and 85° were sent to us by R. R. Wilson as preliminary values on February 27, 1958.

Measurements of Asymmetries in the Decay of Polarized Neutrons*

M. T. BURGY, V. E. KROHN, T. B. NOVEY, AND G. R. RINGO, *Argonne National Laboratory, Lemont, Illinois*

AND

V. L. TELEGDI, *University of Chicago, Chicago, Illinois*

(Received April 17, 1958)

IN an earlier publication,[1] measurements on the decay of polarized neutrons were reported which showed that the decay was not isotropic with respect to the neutron spin. The coefficient for the correlation between the direction of emission of the beta particles and the neutron spin given therein was subsequently shown to be too large in absolute value because of an interference from the correlation of the neutrino direction with the neutron spin.[2] As is clear from the analysis of Jackson, Treiman, and Wyld,[3] the latter correlation might be

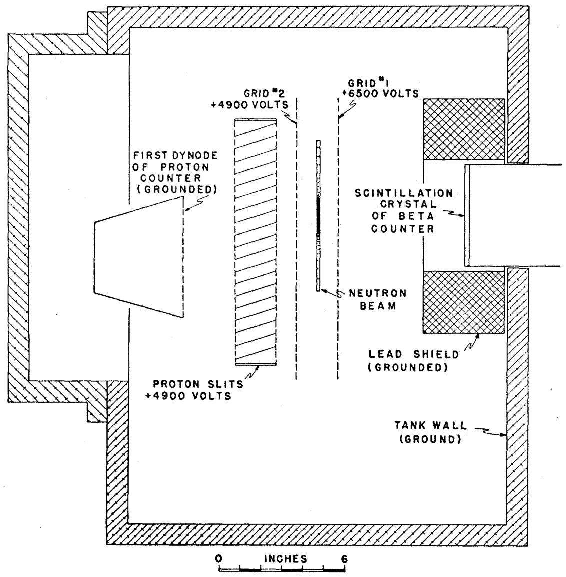

FIG. 1. Vertical cross section (normal to the neutron beam) through the detector system of the experiment measuring the correlation of the neutrino momentum and the neutron spin.

(and in fact turns out to be) large and is one of fundamental interest in beta-decay theory. We therefore decided to measure this latter correlation.

A vertical cross section of the experimental arrangement used is shown in Fig. 1. The means (not shown) for collimating and polarizing the beam (in the vertical direction) were the same as in the first experiment. The conditions of the experiment require the recoil proton to have a downward component of momentum in order that it go through the slits and reach the detector. Thus the neutron disintegrations which are detected are associated predominantly with emission of the neutrino into the upper hemisphere and emission of the electron at approximately 90° to the neutron spin. The results of these measurements are shown in Table I, where the errors quoted in the first line are the statistical ones.

TABLE I. Results of measurements on the correlation between the momentum of the neutrino and the neutron spin; $\omega=1+\mathcal{B}(\mathbf{p}_\nu\cdot\langle\mathbf{J}\rangle/E_\nu J)$.

Beta-energy group (kev)	150–350	350–780
Observed $\mathcal{B}$	0.36±0.04	0.33±0.04
Correction factor for neutrino angular spread	2.00	2.40
Correction factor for imperfections of polarization	1.15	1.15
$\mathcal{B}$	0.83±0.25	0.91±0.19
Average $\mathcal{B}$	0.88±0.15	

There is a possibility that the slits may have a finite reflectivity for protons; if so, this would reduce the observed value of the asymmetry. However, the observed asymmetry is large enough that this effect cannot be very important. $\mathcal{B}$ is the usual correlation coefficient of the cosine of the angle between the directions of interest.[3] The errors quoted for $\mathcal{B}$ are not purely statistical. They arise, in fact, chiefly from uncertainties in the determination of the background.

After this measurement, an improved measurement of the correlation coefficient, $\mathcal{A}$, between the beta-particle momentum and neutron spin was performed. The apparatus was essentially that of Fig. 1 with the slits removed and the direction of polarization of the neutrons made that of a horizontal line in the figure. The results of this measurement give $\mathcal{A}=-0.09$. The estimated error in $\mathcal{A}$ from known sources in this number is ±0.03 but there is a possible additional uncertainty from effects of nonuniformity in the response of the proton detector at different points on its face.

The highest coincidence rates, per beam neutron, which could be obtained in these experiments were roughly two thirds of those to be expected from the known neutron lifetime. These measurements were generally made at about a third of the maximum counting rates in order to suppress background.

The theory of nuclear beta decay being in its simplest sense a description of neutron decay, a complete experimental specification of this process alone should enable one to determine all relevant coupling constants uniquely. While the number of independent experiments is as yet too limited for actually doing this, the nature of the interaction can be deduced from measurements of $\mathcal{A}$ and $\mathcal{B}$ if the following assumptions are granted: (1) GT and F couplings[4] are present in the ratio $|x|=(1.14\pm0.05):1$, but they may be either T and S *or* A and V; (2) the antineutrino is emitted with complete (right *or* left) longitudinal polarization; (3) time-reversal invariance holds. For the possible interactions compatible with these assumptions one predicts, using reference 3, the values for $\mathcal{A}$ and $\mathcal{B}$ listed in Table II.

The present accuracy of the coefficient $\mathcal{A}$ is not great enough to exclude those interactions giving a small positive value for $\mathcal{A}$ and +1 for $\mathcal{B}$. However, the

TABLE II. Predicted values for $\mathcal{A}$ and $\mathcal{B}$.

	$S+T$[a]		$S-T$		$V+A$		$V-A$[a]		
	$\bar{\nu}_L$[b]	$\bar{\nu}_R$	$\bar{\nu}_L$	$\bar{\nu}_R$	$\bar{\nu}_L$	$\bar{\nu}_R$	$\bar{\nu}_L$	$\bar{\nu}_R$	Exp.
$\mathcal{A}$	−1	+1	−0.07[c]	0.07	+1	−1	0.07	−0.07	−0.09
$\mathcal{B}$	−0.07	0.07	−1	+1	−0.07	0.07	−1	+1	+0.88

[a] The relative signs in this row are those of the couplings present; i.e., $V-A$ means $C_A/C_V=-1.14$.
[b] $\bar{\nu}_{L(R)}$ means left (right) handed antineutrino; i.e., $\bar{\nu}_{L(R)}$ corresponds to $C_i/C_i'=-1(+1)$.
[c] The uncertainty of ±0.05 in x introduces an uncertainty of ±0.02 in this number, 0.07, wherever it appears.

measurement of $\mathcal{A}$ for polarized Co^{60} nuclei[5] and the numerous measurements[6] of the longitudinal polarization of beta rays show that $C'_{S,T} \approx -C_{S,T}$ and $C'_{V,A} \approx C_{V,A}$. With these restrictions on the interaction coefficients, the values of $\mathcal{A}$ and $\mathcal{B}$ show that the interaction is predominantly $V-A$. The other interaction combinations give greatly different values. Thus $S+T$ and $V+A$ give $\mathcal{A}=-1$ and $\mathcal{B}\approx 0$, and $S-T$ gives $\mathcal{A}\approx 0$ but $\mathcal{B}=-1$. It must be borne in mind, of course, that the limited accuracy of our data would not enable one to exclude small departures from assumptions (1) and (2) nor even fairly large violations of (3).

Recent experiments with positron emission in A^{35} and K capture in Eu^{152} have also shown that the Fermi interaction[7] is predominantly V and the Gamow-Teller interaction[7,8] is predominantly A. These results are in disagreement with the published analysis[9] of the He^6 experiment which indicate the presence of T.

The $V-A$ interaction is also in agreement with several recent treatments of the theory of beta decay.[10]

* Work performed under the auspices of the U. S. Atomic Energy Commission.

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Beta Decay of the Pion

J. C. Taylor
Imperial College of Science and Technology, London, England
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LET us assume that the hypothesis of a universal (V,A) Fermi interaction, in the form suggested by Feynman and Gell-Mann,[1] will prove to be correct. Then baryons (and perhaps mesons) are coupled to electrons and neutrinos through a current, $j_\mu{}^A + j_\mu{}^V$, consisting of equal amounts of vector and axial vector parts. Feynman and Gell-Mann point out that if $\partial_\mu j_\mu{}^V = 0$, then the close equality between the muon decay coupling constant and the Fermi part of the observed beta-decay constant can be understood. They further remark that if the difference (at present small experimentally) between the Fermi and Gamow-Teller beta-decay couplings should turn out to be zero, then $\partial_\mu j_\mu{}^A = 0$ would be required for similar reasons. It is not known yet whether such a divergenceless axial vector can be constructed, but some preliminary attempts have been reported by Polkinghorne.[2]

This note is to remark that the relation $\partial_\mu j_\mu{}^A = 0$, if it is true, has the additional consequence that $\pi \to e + \nu$ is forbidden. To see this, note that, if one neglects electromagnetic interactions, the amplitude for this decay must have the form

$$C(k^2)k_\mu l_\mu,$$

where

$$l_\mu = \bar{e}\gamma_\mu(1+\gamma_5)\nu,$$

and k_μ is the pion momentum. Thus, kinematically, only the component of the lepton current l_μ parallel to k_μ contributes to the decay. But in the fundamental interaction $j_\mu{}^A l_\mu$, this longitudinal component of l_μ gives no contribution, because $k_\mu j_\mu{}^A = 0$. Thus the amplitude itself must be zero.

The anomalous slowness of π_e decay could be thus explained. But the problem then becomes to explain why π_μ decay *is* seen. Obviously the muon would have to be exempted from at least one of the postulates of the Feynman–Gell-Mann scheme. Certainly the experimental situation on muon capture is not yet such as to prove much similarity to beta decay. Also, it is perhaps an advance to have the point of difficulty shifted from the electron to the (already mysterious) muon.

The author is indebted to T. W. B. Kibble and J. C. Polkinghorne for discussions out of which this note arose.

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Single-Particle Interpretation of Proton Spectra from (d,p) Reactions*

J. P. Schiffer, L. L. Lee, Jr., J. L. Yntema, and B. Zeidman
Argonne National Laboratory, Lemont, Illinois
(Received March 28, 1958)

WHEN the Butler formalism[1] for the deuteron stripping reaction is applied to a (d,p) reaction, it predicts that the amplitude with which a given state of the final nucleus is populated should be proportional to the neutron reduced width $\gamma_n{}^2$ of that state with respect to the ground state of the target nucleus. Utilizing this feature of (d,p) reactions, we have undertaken a study of average reduced neutron widths of bound states. This should be analogous to studies of the