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ON THE DETECTION OF THE FREE NEUTRINO*

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RESTRICTED DATA
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An experiment(1) has been performed to detect the free neutrino. It appears probable that this aim has been accomplished although further confirmatory work is in progress. The cross section for the reaction employed,

$$\nu_- + p \rightarrow n + \beta^+, \qquad (1)$$

has been calculated(2,3) from beta decay theory to be given by the expression:

$$\sigma = \left(\frac{G^2}{2\pi}\right)\left(\frac{h}{mc}\right)^2\left(\frac{p}{mc}\right)^2\left(\frac{1}{v/c}\right) \qquad (2)$$

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(1) Phys. Rev. 90, 492 (1953); 90, 493 (1953).
Important changes from the detector described in this reference include the use of Dumont K1177 photomultiplier tubes and a sodium silicate-titanium dioxide reflecting surface.

(2) E. Konopinski, H. Primakoff (private communications).

(3) We find it convenient to label the neutrino accompanying β^- emission as ν_-, and that accompanying β^+ emission as ν_+.

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

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where

σ = cross section in barns

p,m,v = momentum, mass, and velocity of emitted positron (cgs units)

c = velocity of light (cm/sec)

$2\pi\hbar$ = Planck's constant (cgs units)

G^2 = dimensionless lumped β-coupling constant (= 55 from measurements of neutron and tritium β-decay)(4)

An estimate of the fission fragment neutrino spectrum has been made by Alvarez on the basis of the work of Way and Wigner(5). From this information, we calculated the expected cross section to be $6\text{x}10^{-20}$ barns. Consideration of the momentum balance shows that the positron takes off most of the available energy.

The delayed-coincidence technique employed made use of the positron to produce the first pulse and the γ's from the neutron captured in the Cd loaded scintillator solution for the second pulse(1). The predicted first pulse spectrum due to the positron has a threshold at 1.02 Mev, assuming both annihilation gammas are collected, rises to a maximum at a few Mev and falls towards zero with increasing energy, vanishing in the vicinity of 8 Mev. Neutron capture times in the vicinity of 5 usec were employed.

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(4) E. J. Konopinski and L. M. Langer, Annual Review of Nuclear Science, (Annual Reviews, Inc., Stanford, California, 1953), Vol. 2, p. 261.

(5) L. W. Alvarez, UCRL-328 (1949); K. Way and E. P. Wigner, Phys. Rev. 73, 1318 (1948). Work in progress at this laboratory tends to indicate that these predictions are low.

The detector was set up in the vicinity of the face of a Hanford reactor(6) and was surrounded on all sides by a shield comprised of 4 to 6 feet of paraffin alternated with 4 to 8 inches of Pb. In order to minimize the effects of tube noise and to eliminate the counting of individual tube after-pulses, the 90 photomultipliers were divided into two banks of 45. The signal from each bank was amplified by a corresponding linear amplifier and fed to two independent pulse-height selecting gates, one of which was set to accept pulses characteristic of the positron signal and the other to accept those characteristic of the neutron-capture gammas. The output pulses from the two "positron" gates were then fed to a coincidence circuit with a resolving time of 0.3 microsecond, and those from the two "neutron" gates to a similar circuit. When a pulse appeared at the output of the "positron" coincidence circuit, an 18 channel time-delay analyzer (with 0.5 microsecond channel widths) was triggered. If a second pulse then appeared at the output of the "neutron" coincidence circuit within nine microseconds after this, a count was registered in the appropriate channel, recording in this manner the number of "delayed-coincidences" obtained and the delay time for each. The amplitude of the first or "positron" pulse was simultaneously recorded for each delayed pair by delaying all signals from one of the banks in a third linear amplifier and then impressing them on a ten-channel pulse-height analyzer which was gated whenever a delayed-

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(6) Our estimate of the ν- flux at the detector is at present classified and hence cannot be given here.

coincidence was obtained. The expected delayed-coincidence rate, allowing for detector efficiencies and for gate settings, was 0.1 - 0.3 counts/minute. The apparatus was checked using a double-pulser designed for the purpose and by observing cosmic-ray μ-meson decay within the detector. The system was energy calibrated using a Co^{60} source in the center of the detector as well as by the N^{16} activity in water piped from within the pile to around the detector.

An appreciable delayed-coincidence background ($\sim$5 c/min) was observed which was independent of pile power. The function, delayed-pair rate per unit time vs. delay time, which was obtained for many background delayed-pair counts, rises from zero at the origin to a maximum at about 3.5 microseconds and then tails exponentially characteristic of the Cd concentrations used, following closely the predicted function obtained in a Monte Carlo calculation for neutron capture in the detector. As the energy of the second pulse of each pair was also characteristic of the gamma radiation from neutron capture in Cd, it may be assumed that the second event of each pair was due to the presence of a neutron in the detector.

A covering GM blanket which reduced the μ-meson counting rate by 75 percent when turned on in anticoincidence reduced this delayed pair rate insignificantly. A six-foot thick water shield installed above the detector and capable of absorbing at least 30 percent of the cosmic-ray nucleonic component also failed to change the delayed-pair rate significantly. Subsequent work in an underground location in which the cosmic ray background is greatly diminished indicates that the Hanford background is probably due to cosmic rays, for example, neutrons arising from μ^- capture in shield materials, stars which include neutrons and gamma rays energetic enough to create electron-positron pairs, showers, etc.

The change in delayed-coincidence counting rate when the pile went from full power to zero power was detected only for a first pulse gate setting of from 2 to 5 Mev. The accidental background obscured the pile signal below 2 Mev. Table I lists details of the various runs. Least squares fits of the observed counting rates in the delayed-time channels lead to the following results:

Pile up: (four runs totalling 10,000 seconds) --	2.55 ± 0.15	delayed	c/min.
Pile down: (three runs totalling 6,000 seconds)	2.14 ± 0.13	"	"	"
Difference due to the pile:	0.41 ± 0.20	"	"	"

This difference is to be compared with the predicted ~1/5 c/min due to neutrinos, using an effective cross section of ~6×10^{-20} barns for the process. It is to be remarked that a small channel overlap in the time delay analyzer would be reflected in an amplified percentage decrease in the pile difference number. Measurements of the number of fast neutrons leaking from the pile face made with nuclear emulsion plates and consideration of the detector shielding employed rules out neutron-proton recoils as causing this difference.

A more detailed report is in preparation. It is difficult to properly acknowledge the many contributions to all phases of this experiment. We wish to thank our colleagues: E. C. Anderson, L. J. Brown, D. Carter, F.

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TABLE I

LISTING OF DATA

RUN	PILE STATUS	LENGTH OF RUN (SECONDS)	NET DELAYED PAIR RATE c/m	ACCIDENTAL BACKGROUND RATE c/m
1	Up	4000	2.56	0.84
2	Up	2000	2.46	3.54
3	Up	4000	2.58	3.11
4	Down	3000	2.20	0.45
5	Down	2000	2.02	0.15
6	Down	1000	2.19	0.13

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