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Absorption of Negative Pions in Deuterium: Parity of the Pion*

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The reaction $\pi^-+d\rightarrow 2n$ has been observed by detecting the two neutrons in coincidence with slow negative mesons incident on a liquid deuterium target. The observed angular correlation of the two neutrons confirms the identification of the process. The process is therefore not forbidden, and this fact may be used to establish the odd relative parity of the pion and the nucleon.

I. INTRODUCTION

IT was first pointed out by Ferretti[1] that the capture in deuterium of negative mesons at rest might furnish a means of distinguishing between scalar and pseudoscalar pions. The reaction,

$$\pi^-+d\rightarrow 2n, \tag{1}$$

is forbidden for scalar mesons in S states since requirements of angular momentum and parity conservation and the Pauli principle cannot simultaneously be satisfied. The argument is independent of the theoretical model for the process. If the reaction is observed, then to rule out scalar parity for the pion, it is only necessary to show that the reaction proceeds indeed from an S state. Brueckner, Serber, and Watson[2] have shown, using the measured cross section for the process $\pi^++d\rightarrow 2p$, extrapolated to lower energy, that capture from the excited states of the meson-deuteron atom does not compete favorably with electromagnetic de-excitation. At most, one in thirty mesons is expected to be captured before reaching the ground state. Therefore, if more than one-thirtieth of the stopped mesons are captured according to process (1), the meson cannot be scalar. Since it has already been shown that the pion has zero spin,[3,4] the pion is then pseudoscalar.

The only previous evidence for reaction (1) is furnished by the experiments of Panofsky, Aamodt, and Hadley.[5] In these experiments measurements were made on the energy spectra of γ rays from hydrogen and deuterium gases at 3000 lb/sq. in. pressure and 78°K in which mesons had come to rest. All reactions in hydrogen give γ rays, either directly or through π^0 decay. The γ-ray yield from deuterium was lower and left 70 percent of the capture processes unaccounted for. This was interpreted to mean that 70 percent of the captures proceed through reaction (1).

In view of the important consequences of this result, we have performed an experiment in which the two neutrons are observed in coincidence and in coincidence with incident mesons some of which come to rest in a container of liquid deuterium. This provides a direct observation of the process (1) and confirms the conclusions of Panofsky *et al.*

II. EXPERIMENTAL ARRANGEMENT

Negative mesons produced at the internal target of the Columbia University 390-Mev cyclotron are collimated in a channel of the 8-foot iron shielding wall and further analyzed by a double focusing magnet and the beam defining counters No. 1 and No. 2. (See Fig. 1.) Counter No. 1 is a liquid scintillator $4\frac{1}{2}$ inches in diameter and $\frac{5}{8}$ inch thick; counter No. 2 is a stilbene crystal $2\frac{1}{4}$ inches horizontally, $2\frac{3}{4}$ inches vertically, and $\frac{1}{8}$ inch in thickness. Between counters No. 1 and No. 2 a 2 g/cm² carbon absorber is inserted, with 5 g/cm² of LiH and 2.7 g/cm² of polyethylene between counter No. 2 and the deuterium target. The absorber thickness is chosen to maximize the number of mesons which stop in the deuterium; the type of material to minimize Coulomb scattering, consistent with convenience.

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1 B. Ferretti, in Report of an International Conference on Low Temperatures and Fundamental Particles (The Physical Society, London, 1946), Vol. 1, p. 75.

2 Brueckner, Serber, and Watson, Phys. Rev. **81**, 575 (1951).

3 Durbin, Loar, and Steinberger, Phys. Rev. **83**, 646 (1951).

4 Clark, Roberts, and Wilson, Phys. Rev. **83**, 649 (1951).

5 Panofsky, Aamodt, and Hadley, Phys. Rev. **81**, 565 (1951).

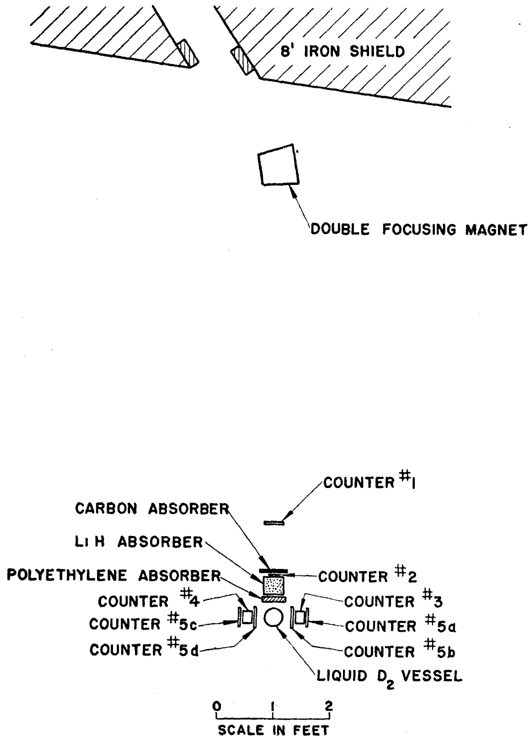

FIG. 1. Experimental arrangement used to detect neutron-neutron coincidences.

The hydrogen target previously described[6] is used here with liquid deuterium in the scattering chamber. The only modification required is the insertion of a plug to prevent communication between the hydrogen and deuterium reservoirs. The D_2 intake is connected to the gaseous-deuterium filling system shown in Fig. 2. Before liquefaction the pressure of the gas in the 115 gallon reservoir is 21 lb/sq. in. On admission to the target the gas is cooled by passing successively through copper coils in the liquid nitrogen and hydrogen reser-

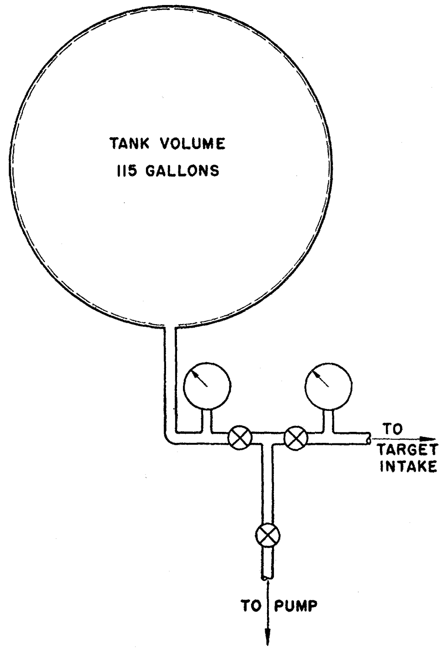

FIG. 2. Gaseous-deuterium filling system.

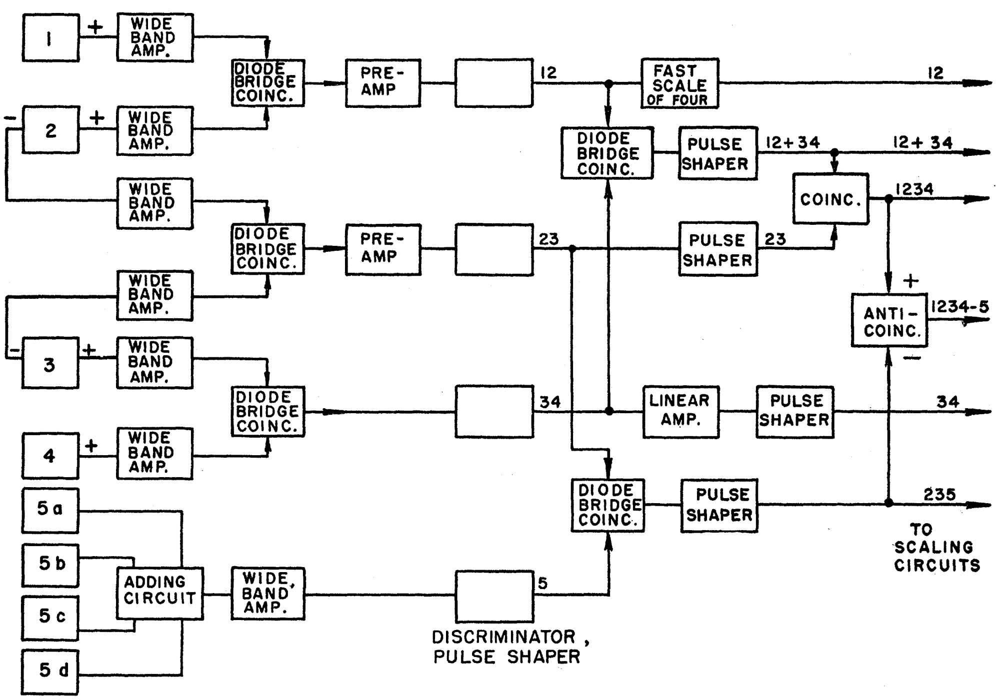

FIG. 3. Block diagram of electronics.

[6] Bodansky, Sachs, and Steinberger, Phys. Rev. **93**, 1367 (1954).

voirs. When equilibrium is reached, approximately $\frac{1}{2}$ liter of liquid has accumulated and the pressure of the deuterium system is 5 lb/sq. in. The liquid deuterium in the reservoir can be admitted to the target cup and returned in the manner previously described. At the conclusion of the experiment, the hydrogen is allowed to evaporate and the deuterium returns to the gas reservoir.

Counters No. 3 and No. 4, the neutron detectors, are liquid scintillators $2\frac{1}{2}$ inches in diameter and 2 inches thick along the direction of motion of the neutrons. Counters 5 *a*, *b*, *c*, and *d* are plastic scintillators $4\frac{1}{2}$ inches in diameter and $\frac{1}{2}$ inch thick. The center of each neutron counter is $5\frac{3}{8}$ inches from the center of the target cup. The six counters of the detection system have a common axis passing through the center of the target cup.

An "event" constitutes a coincidence 1234 in anticoincidence with the parallel connection of the set of four counters No. 5. (See Fig. 3.) The neutrons are detected by means of stars or proton recoils made in No. 3 and No. 4. The discriminator on the 34 coincidence is adjusted so that pulses in No. 3 and No. 4 are rejected if the energy loss due to ionization is less than roughly 10 Mev. Charged particles are rejected in counters No. 5*b* and No. 5*d*. Low-energy γ rays are rejected by the pulse-height requirement and high-energy γ rays converted in No. 3 and No. 4 are rejected in counters No. 5*a* and No. 5*c*. The system is specific for the detection of *n-n* coincidences with neutron energy greater than approximately 10–20 Mev. The efficiency for detection can be estimated from information on the *n-p* cross section[7] and star formation in carbon.[8] These experimental results yield a probability $\epsilon_n = 0.065 \pm 0.015$ for the formation by 70-Mev neutrons, of charged secondaries with energy sufficient to register a 34 coincidence.

TABLE I. *n-n* coincidences observed with geometry of Fig. 1. Rates are per 10^6 incident mesons as measured in 12 coincidence.

	Counts with D_2 in cup	Counts with cup empty	Net due to D_2
1234	1.02 ± 0.19	0.08 ± 0.1	0.94 ± 0.20
1234−5	0.70 ± 0.16	0.08 ± 0.1	0.62 ± 0.19

III. EXPERIMENTAL RESULTS

A. The Process $\pi^- + d \rightarrow 2n + \gamma$[9]

We have used the γ rays of this reaction in order: (1) to determine the thickness of the absorber in the incident beam which maximizes the number of mesons which come to rest in the target, and (2) to permit an estimate

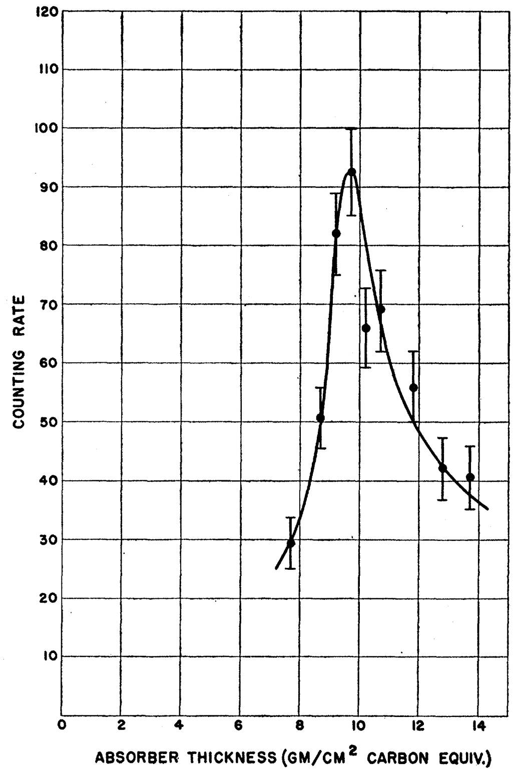

FIG. 4. Counting rate of γ rays from the reaction $\pi^- + d \rightarrow 2n + \gamma$ *vs* thickness of absorber in the incident beam.

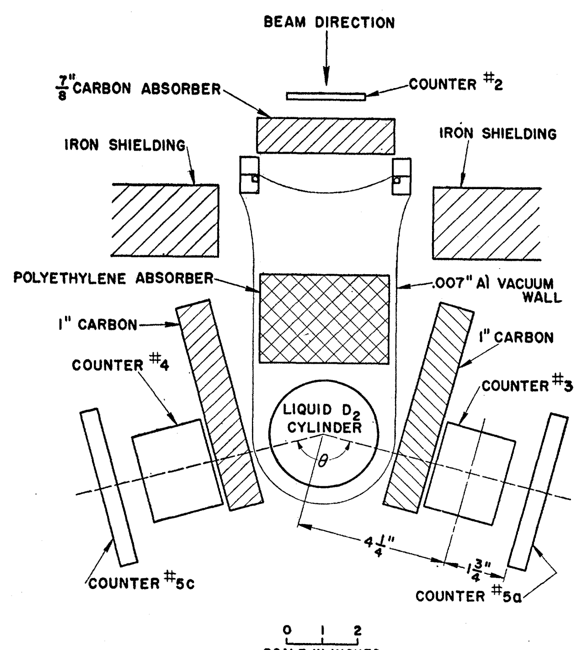

FIG. 5. Experimental geometry used to measure *n-n* coincidence rate as a function of the angle θ between the neutron detectors.

[7] Hadley, Kelly, Leith, Segrè, Wiegand, and York, Phys. Rev. **75**, 351 (1949).

[8] D. A. Kellogg, Phys. Rev. **90**, 224 (1953).

[9] The reaction $\pi^- + d \rightarrow 2n + \pi^0 \rightarrow 2n + 2\gamma$ is improbable (reference 5). In an experiment which will be reported at a later time we have shown that this process occurs in less than 0.1 percent of the cases of absorption.

to be made of the ratio R of the nonradiative to radiative capture rates, $R=(\pi^-+d\rightarrow 2n)/(\pi^-+d\rightarrow 2n+\gamma)$. To detect the γ rays, counter No. 3 is replaced by an absorber, 1.8 g/cm^2 of polyethylene, with a converter of 7 g/cm^2 of Pb directly in front of counter 5*b*. The circuits are arranged to record coincidences 12 and 125*a*5*b*. The product of solid angle and efficiency for this arrangement is $\epsilon_\gamma\Omega_\gamma=0.20$. The 125*a*5*b* rate as a function of the absorber thickness is shown in Fig. 4. The absorber used in the following experiments is 9.7 g/cm^2. For this absorber thickness the γ ray counting rate is

$$CR_{2n+\gamma}=\frac{125a5b}{12}=(488\pm5)\times10^{-6}.$$

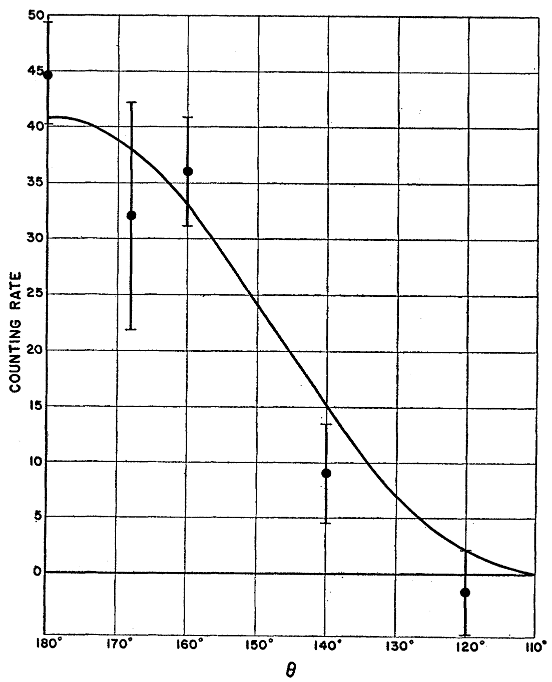

FIG. 6. Observed and calculated *n-n* coincidence counting rates *vs* the angle subtended by the two neutron detectors at the target.

B. *n-n* Coincidences

The results of the search for *n-n* coincidences with the geometry of Fig. 1 and the electronic arrangement of Fig. 3 are given in Table I. The observed 2*n* rate

$$CR_{2n}=\frac{(1234)-5}{12}=(0.62\pm0.19)\times10^{-6}.$$

The ratio R is

$$\frac{CR_{2n}}{CR_{2n+\gamma}}\times\frac{\epsilon_\gamma}{(\epsilon_n)^2}\times\frac{\Omega_\gamma/4\pi}{(\Omega_n/2\pi)g}.$$

The quantity g is a geometrical factor; it is the probability that one of the two neutrons traverse counter No. 3 if it is known that the other has traversed counter No. 4 and that the two neutrons were emitted at 180° to each other. The quantity g was computed numerically to be 0.12. With the values $\epsilon_\gamma\Omega_\gamma=0.20$, $\epsilon_n=0.065\pm0.015$, and $\Omega_n=0.17$, then $R=1.5\pm0.8$. This is quite similar to the value $R=2.4\pm0.5$ obtained by Panofsky *et al.* from a comparison of the γ-ray yields in hydrogen and deuterium. The discrepancy is within the experimental uncertainties.

C. *n-n* Angular Correlation

To test the identification of the observed events, we have measured the coincidence rate as a function of the angle subtended by the two neutron detectors at the target. This was, however, physically impossible with the arrangement of Fig. 1. It was necessary to sacrifice the anticoincidence counters 5*b* and 5*d* to obtain the required mobility without reducing the counting rate to an impossible value. The new geometry is shown in Fig. 5. The additional absorber serves to make the system insensitive to low-energy charged particles and the remaining anticoincidence counters reject high-energy γ rays. The results are shown in Fig. 6. The theoretical curve represents the response of the detection system to particles emerging with equal probability from the various volume elements of the deuterium and at 180° to each other. The consistency of the experimental points with the calculated function confirms the identification of the events as *n-n* coincidences.