# Letters to the Editor

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## The Absorption of Pions by Deuterons*

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THE study of the absorption of positive pions by deuterons, which, together with its inverse, has been used to determine the spin of the meson,[1,2] has been extended. We present here results on the energy dependence of the angular distribution and of the total cross section, in the hope that they will prove useful in the attempt to understand the pion-nucleon interaction.

The reaction is $\pi^++d\rightarrow p+p$. The reaction rate is determined by the rate of recoil proton pairs in coincidence with incoming mesons, incident successively on water and heavy water targets. The experimental technique has already been described.[1] The water cells are 1″ thick along the beam direction. The energy dispersion due to target thickness and meson beam inhomogeneity is approximately $\pm 7$ Mev. The angular dispersion is approximately $\pm 14°$. Despite this poor resolution the coincidence rate of recoil protons is only $\sim$1/minute in the Nevis meson beam of $\sim$500/sec. The uncertainties in the result are almost entirely statistical; the geometrical factors have been calculated with greater accuracy, and the combined uncertainties in counting efficiency and beam composition are less than 10 percent.

The results are given in Table I. All parameters as well as differential cross sections are in the center of mass system. The recoil angles listed are averaged over the angular dispersion. This affects only the angles near 90°, since, because of the symmetry, 90° is the extreme angle, and larger angles are recorded as smaller angles. When the proton counter axes are set at 90° relative to the meson beam, the average detection angle is 83°.

It is possible to represent the angular dependence as $\alpha+\beta\cos^2\theta$, since meson angular momenta with respect to the deuteron of more than two Planck units should not contribute appreciably at these energies. The best fits to such a distribution are given in Table II, together with absolute cross sections.

In Table II we have also included the results of Cartwright, Richman, Wilcox, and Whitehead.[3] The angular distribution found at Berkeley and our results are only in fair agreement.

There is no large change in the angular distribution in the energy range 25–53 Mev for the incident meson in the center of mass system. The total cross section increases by a factor $2.25\pm 0.32$.

To see the implication of this result on the meson nucleon interaction, it is necessary to separate the effects of the nuclear binding in initial and final states as well as the kinematical factors. The effects of the binding on the angular distribution are complicated, and are discussed in the following note.[4] The kinematical factors are

TABLE I. Differential cross sections for the absorption of pions by deuterons in the center of mass system. Rms statistical errors are given.

| $E_m=25$ Mev | | $E_m=40$ Mev | | $E_m=53$ Mev | |
|---|---|---|---|---|---|
| $\theta_{cm}$ | $d\sigma/d\Omega$ cm²/sterad | $\theta_{cm}$ | $d\sigma/d\Omega$ | $\theta_{cm}$ | $d\sigma/d\Omega$ |
| 29° | $8.5\pm1.1\times10^{-28}$ | 30° | $17.4\pm2.6\times10^{-28}$ | 30° | $20.1\pm4\times10^{-28}$ |
| 35° | $7.3\pm1.6$ | 50° | $9.2\pm1.5$ | 60° | $5.7\pm1.8$ |
| 45° | $7.5\pm2.2$ | 70° | $8.4\pm2.4$ | 83° | $5.5\pm2.1$ |
| 50° | $7.1\pm0.9$ | 83° | $4.0\pm1.7$ | ... | ... |
| 82° | $1.7\pm0.6$ | ... | ... | ... | ... |

TABLE II. Total cross sections and best fit angular distributions for the data in Table I.

| $E_{cm}$ | Angular distribution | Total cross section |
|---|---|---|
| 21.5 Mev[a] | $10.7(\cos^2\theta+0.07)\times10^{-28}$ sterad/cm² | $2.8\pm0.8\times10^{-27}$ cm² |
| 25 Mev | $9(\cos^2\theta+0.22)\times10^{-28}$ sterad/cm² | $3.1\pm0.3\times10^{-27}$ cm² |
| 40 Mev | $18(\cos^2\theta+0.2)\times10^{-28}$ sterad/cm² | $6.1\pm0.6\times10^{-27}$ cm² |
| 53 Mev | $21.5(\cos^2\theta+0.18)\times10^{-28}$ sterad/cm² | $7.0\pm0.7\times10^{-27}$ cm² |

[a] We include the result of the Berkeley group on the inverse reaction, inverted on the basis of the law of detailed balance and zero spin for the pion.

$K$ = momentum space/(relative velocity of incoming nucleons $\times$ total meson energy).

The factor 1/total meson energy is not strictly a kinematical factor; it is due to the normalization of the meson wave and is included because it is omitted in the theoretical analysis which follows this letter.

$$k_{53}/k_{25}=0.71.$$

The average square of the matrix element for the process therefore increases by the factor $2.3/0.71=3.25\pm45$ in the energy range 25–53 Mev. This is a considerable increase, especially since the effects of binding also decrease the cross section at higher relative to lower meson energy. This effect is approximately

$$|f(k_{f53})/f(k_{f25})|^2,$$

where $f(k_{f53})$ is the fourier amplitude of the deuteron or the diproton wave function for the momentum of one of the recoil protons resulting in the absorption of a 53-Mev meson. These fourier amplitudes decrease at least as $1/k^2$ and probably more nearly as $1/k^5$ for such large momenta. If this factor is also taken into account, then the meson-nucleon interaction must increase by a factor $\sqrt{4.5}-\sqrt{6}$ in the meson energy interval 25–53 Mev. The meson momentum increases by the factor 1.53 in this interval so that the meson nucleon interaction must increase approximately as the square of the momentum of the meson. This is of course a stronger momentum dependence than the linear dependence predicted in pseudoscalar theory with pseudovector coupling. Other theories predict an even weaker dependence and are also in conflict with other experiments. The steep energy dependence is probably of the same origin as the steep excitation function in neutral photomeson production[5,6] and may be due to some resonance effect, as has already been suggested in connection with the photomeson experiments.[7,8]

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[4] Chew, Goldberger, Steinberger, and Yang, Phys. Rev. **84**, 581 (1951).
[5] A. Silverman and M. Stearns, Phys. Rev. **83**, 853 (1951).
[6] Panofsky, Steinberger, and Stellar (to be published).
[7] K. Brueckner and K. Case, Phys. Rev. **83**, 1141 (1951).
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## A Theoretical Analysis of the Process $\pi^++d\rightleftharpoons p+p$

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THE experiment described in the preceeding letter[1] as well as those on the inverse reaction, the production of mesons in the collision of two protons, may be analyzed in the spirit of