On the Reactions $\pi^+ + d \leftrightarrows p + p$*

W. B. CHESTON
University of Rochester, Rochester, New York
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The reactions $\pi^+ + d \leftrightarrows p + p$ have been investigated in weak-coupling approximation. Using detailed balancing arguments it is shown that comparison of the total cross sections for both processes at appropriate energies allows a unique determination of the spin of the charged π-meson independent of weak coupling theory. It is also shown that the angular distributions of the final state particles and the energy variation of the total cross sections also provide information as to the charged π-meson spin.

1. INTRODUCTION

COMPARISON of the theoretical predictions[1] regarding the absorption of a π^- meson from the K shell of the mesic-deuterium atom with the observed ratio of 2 to 1 for nonradiative to radiative absorption[2] leads to the conclusion that the charged π-meson is either pseudoscalar (spin zero and odd parity) or pseudovector (spin one and even parity). This conclusion follows from quite general selection rules associated with the properties of a π^- meson in a K shell rather than from detailed quantitative predictions of weak-coupling theory. It is clear that at sufficiently low energies (say, below 5 Mev) the same selection rules operate for the absorption of π^+ mesons by deuterons and nonradiative and radiative absorption complete on almost equal terms. However, if an experiment is carried out for π^+ energies greater than 5 Mev (which is experimentally more feasible) the nonradiative process $\pi^+ + d \rightarrow p + p$ becomes dominant and of great interest for studying the properties of the π^+ meson.

In this paper we treat the reaction $\pi^+ + d \rightarrow p + p$ phenomenologically and compute both the total cross section as a function of energy and the angular distribution of the two final protons for the fields and couplings considered by Tamor[1] [$S(S)$, $PS(PS)$, $PS(PV)$, $V(V)$, and $PV(PV)$]. We restrict ourselves to meson energies greater than 5 Mev[3] but low enough (say, less than 100 Mev) so that the nucleons can be treated nonrelativistically. We also calculate the cross section for the inverse reaction $p + p \rightarrow \pi^+ + d$ at corresponding energies and determine the angular distribution of the π^+ mesons in the laboratory system.[4] It will be shown that the method of detailed balancing applied to the two reactions permits a unique determination of the spin of the π^+ meson.

2. THE REACTION $\pi^+ + d \rightarrow p + p$

We perform a first-order phenomenological calculation similar to that used by Tamor[1] in his investigation of the analogous process of the absorption of the π^- meson from the K shell of the mesic-deuterium atom. The matrix element M for the absorption of a π^+ meson by the deuteron may be written:

$$M = \int \Psi_f^*(\mathbf{r}_1, \mathbf{r}_2; \boldsymbol{\sigma}_1, \boldsymbol{\sigma}_2; \boldsymbol{\tau}_1, \boldsymbol{\tau}_2)\vartheta(\mathbf{r}_1, \mathbf{r}_2; \boldsymbol{\sigma}_1, \boldsymbol{\sigma}_2; \boldsymbol{\tau}_1, \boldsymbol{\tau}_2) \times \Psi_0(\mathbf{r}_1, \mathbf{r}_2; \boldsymbol{\sigma}_1, \boldsymbol{\sigma}_2; \boldsymbol{\tau}_1, \boldsymbol{\tau}_2) d\mathbf{r}_1 d\mathbf{r}_2 \quad (1)$$

where $\mathbf{r}_i$, $\boldsymbol{\sigma}_i$, $\boldsymbol{\tau}_i$ are the space, spin, and isotopic spin of the ith nucleon; ϑ is the operator which takes the two nucleon system in the initial state (deuteron) into the

TABLE I. Meson-nucleon interaction operators.

Theory	Interaction operator	Nonrelativistic approximation
$S(S)$	$(4\pi)^{\frac{1}{2}} g\beta\phi$	$(4\pi)^{\frac{1}{2}} g\phi$
$PS(PS)$*	$i(4\pi)^{\frac{1}{2}} f'\beta\gamma^5\phi$	$i(4\pi)^{\frac{1}{2}} \frac{f'}{2}\left\{\boldsymbol{\sigma}\cdot\mathbf{k} - \frac{E-2J(r)\Lambda}{2}\boldsymbol{\sigma}\cdot(\mathbf{p}^f+\mathbf{p}^0)\right\}\phi$
$PS(PV)$	$i(4\pi)^{\frac{1}{2}} \frac{f}{\mu}\beta\gamma^5\gamma_\mu \frac{\partial}{\partial x_\mu}\phi$	$-i(4\pi)^{\frac{1}{2}} \frac{f}{\mu}\left\{\boldsymbol{\sigma}\cdot\mathbf{k} - \frac{E}{2}\boldsymbol{\sigma}\cdot(\mathbf{p}^f+\mathbf{p}^0)\right\}\phi$
$V(V)$	$i(4\pi)^{\frac{1}{2}} g'\beta\gamma_\mu\phi_\mu$	$(4\pi)^{\frac{1}{2}} \frac{g'}{2}\left\{\left(\mathbf{p}^f+\mathbf{p}^0-\frac{2}{E}\mathbf{k}\right)\cdot\boldsymbol{\phi} + i\boldsymbol{\sigma}\cdot(\mathbf{p}^f-\mathbf{p}^0)\times\boldsymbol{\phi}\right\}$
$PV(PV)$	$i(4\pi)^{\frac{1}{2}} f''\beta\gamma^5\gamma_\mu\phi_\mu$	$(4\pi)^{\frac{1}{2}} f''\boldsymbol{\sigma}\cdot\boldsymbol{\phi}$

* The equivalence theorem between the $PS(PS)$ and $PS(PV)$ theories does not hold because the potential contains charge exchange operators [see F. J. Dyson, Phys. Rev. **73**, 929 (1948)]. We have assumed that the two nucleon potential may be written:

$$V(\mathbf{r}, \boldsymbol{\sigma}, \boldsymbol{\tau}) = \tfrac{1}{2}(1+P_M)J(r),$$

where P_M is the Majorana operator.

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[1] S. Tamor, Phys. Rev. **82**, 38 (1951).

[2] Aamodt, Hadley, and Panofsky (private communication).

[3] This has the additional advantage that the coulomb barrier of the deuteron may be neglected.

[4] The angular distribution in the c.m. system is the same for the inverse reaction (see below).

TABLE II. Differential cross section for the reactions $\pi^+ + d \leftrightarrows p + p$ in the c.m. system.

Type of meson-nucleon coupling	$dN(\theta)/d(\cos\theta)$ unnormalized
$S(S)$	$\{a_- - a_+\}^2$
$PS(PS)$	$\{2\lvert[E\mathbf{K}+\boldsymbol{k}]a_+ + [\mathbf{K}-\frac{1}{2}\boldsymbol{k}]c_+\rvert^2$ $+2\lvert[E\mathbf{K}-\boldsymbol{k}]a_- + [\mathbf{K}+\frac{1}{2}\boldsymbol{k}]c_-\rvert^2$ $+4([E\mathbf{K}+\boldsymbol{k}]a_+ + [\mathbf{K}-\frac{1}{2}\boldsymbol{k}]c_+)\cdot([E\mathbf{K}-\boldsymbol{k}]a_- + [\mathbf{K}+\frac{1}{2}\boldsymbol{k}]c_-)$ $+\lvert[E\mathbf{K}+\boldsymbol{k}]\rvert^2 a_+^2 + \lvert[E\mathbf{K}-\boldsymbol{k}]\rvert^2 a_-^2 + 2[k^2-E^2K^2]a_+a_-\}$
$PS(PV)$	$\{3\lvert E\mathbf{K}+\boldsymbol{k}\rvert a_+^2 + 3\lvert E\mathbf{K}-\boldsymbol{k}\rvert a^2$ $-2[k^2-E^2K^2]a_+a_-\}$
$V(V)$	$(1/E^2)\{\lvert E\mathbf{K}+\boldsymbol{k}\rvert^2 a_+^2 + \lvert E\mathbf{K}-\boldsymbol{k}\rvert^2 a_-^2 - 2[k^2-E^2K^2]a_+a_-\}$
$PV(PV)$	$\{3a_-^2+3a_+^2-2a_+a_-\}$

final state (two protons) and represents the absorption of a π^+ meson; Ψ_0; Ψ_f are the wave functions of the initial and final states of the two nucleon system. For Ψ_f we chose appropriately antisymmetrized plane wave functions neglecting the interaction of the two nucleons in the final state, which is assumed small because of the high kinetic energy (>70 Mev) of the final protons.[5] In considering Ψ_0 we note that the deuteron ground state is predominantly $^3S_1$ with a few percent admixture of $^3D_1$. We shall first neglect the $^3D_1$ contribution to Ψ_0 and estimate the error introduced later. For the space part of $\Psi_0(r)$, we chose therefore the S-state solution of Schrödinger's equation corresponding to Hulthen's potential:

$$V(r)=\frac{\gamma^2-\beta^2}{e^{(\beta-\gamma)r}-1};\quad \Psi_0(r)=\frac{N}{(4\pi)^{\frac{1}{2}}}\frac{e^{-\gamma r}-e^{-\beta r}}{r}\,|\,\text{triplet}\rangle$$

where γ = reciprocal radius of the deuteron; and β is defined in terms of r_0, the effective range of nuclear forces, thus:

$$r_0=2/(\gamma+\beta)-1/\beta.$$

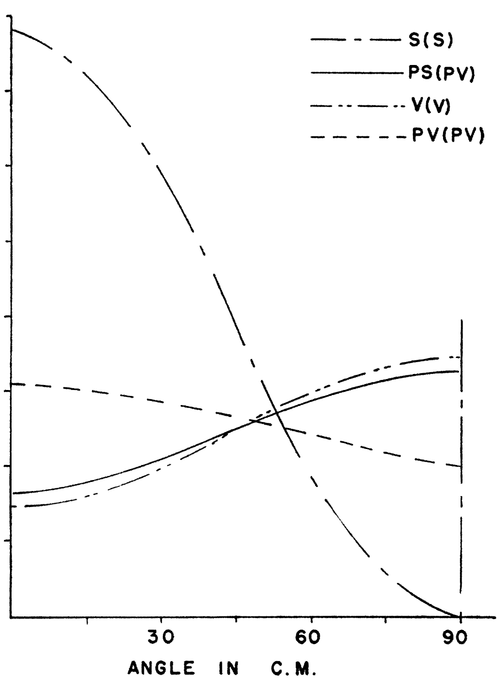

FIG. 1. Angular distribution of protons in c.m. system for absorption of 22.7 Mev π^+ mesons by the deuteron. The $^3D_1$ contribution to the deuteron ground state is neglected.

Since our calculation is phenomenological and treats the two nucleons nonrelativistically, it is necessary to find nonrelativistic expressions for the meson-nucleon interaction operators which are valid to first order in v/c of the nucleons. The nonrelativistic approximations to those interactions which contain only even operators, i.e., $S(S)$ and $PV(PV)$ are immediate. For those interactions which contain odd operators, i.e., $PS(PS)$,[6] $PS(PV)$, and $V(V)$ the method we use is due to Foldy and Wouthuysen.[7] The nonrelativistic approximations for the various theories are given in Table I. The

TABLE III. Differential cross section for the reactions $\pi^+ + d \leftrightarrows p + p$ in the c.m. system evaluated for four different incident π^+ kinetic energies (laboratory system).

$\sigma(0°):\sigma(45°):\sigma(90°)$.[a]

π Kinetic energy (Mev) / Theory	5		22.7		50		100	
	45°	90°	45°	90°	45°	90°	45°	90°
$S(S)$	0.49	0	0.47	0	0.44	0	0.38	0
$PS(PS)$[b]			1.18	1.23				
$PS(PV)$	1.13	1.26	1.52	1.97	1.80	2.33	1.88	2.22
$V(V)$	1.10	1.19	1.71	2.33	5.12	7.90	6.01	8.40
$PV(PV)$	0.96	0.92	0.84	0.70	0.71	0.48	0.56	0.27

[a] All values normalized to $\sigma(0°)=1$.
[b] Values in this table and Tables V and VII for the $PS(PS)$ theory were calculated using $J(r)=-V_0e^{-\alpha r}/\alpha r$. The values of V_0 and α used are based on a value of $r_0=1.74\times10^{-13}$ cm. [Hughes, Burgy, and Ringo, Phys. Rev. **77**, 291 (1950); Hughes, Phys. Rev. **78**, 315 (1950).]

[5] The effect of the distortion of the final wave function caused by the interaction of the two protons was estimated and found to change the total and differential cross sections by at most a few percent.

[6] It should be noted that a phenomenological calculation employing the $PS(PS)$ theory is likely to lead to misleading results if nuclear forces are due to an exchange of virtual mesons. This follows because for the $PS(PS)$ theory, the exchange terms (i.e., the terms involving the absorption of the real meson between the emission and absorption of the virtual mesons) dominate the nonexchange terms and when the nuclear force is replaced by a potential, these exchange terms are ignored. Nevertheless, we give some results for the $PS(PS)$ theory for the sake of comparison.

[7] L. Foldy and S. Wouthuysen, Phys. Rev. **78**, 29 (1950).

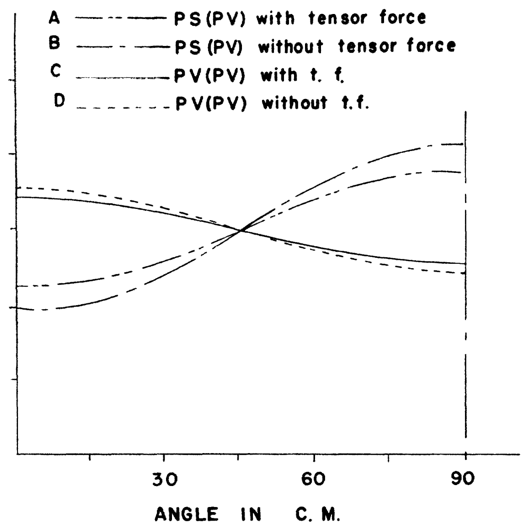

FIG. 2. Angular distribution of protons in c.m. system for absorption of 22.7-Mev π^+ mesons by the deuteron. Curves *A* and *C* include the $^3D_1$ contribution for the *PS*(*PV*) and *PV*(*PV*) theories respectively, whereas curves *B* and *D* neglect the $^3D_1$ contribution for the *PS*(*PV*) and *PV*(*PV*) theories.

symbols in Table I are defined as: ϕ=meson wave function (incoming plane wave); $\mathbf{k}$=meson momentum; E=meson energy; $\boldsymbol{\sigma}$=Pauli spin matrix; $\mathbf{p}^0$, $\mathbf{p}^f$=initial and final nucleon momenta; $\hbar=c=M=1$. Λ is defined by: $\langle\text{triplet}|\Lambda=\langle\text{triplet}|$; $\langle\text{singlet}|\Lambda=0$. For the process to occur, the interaction operators must be symmetrized with respect to the space, spin, and isotopic spin coordinates of the two nucleons. Since the initial state is antisymmetric in isotopic spin and the final state symmetric in this coordinate, the interaction operators must be antisymmetrized in the space and spin coordinates of the two nucleons. The angular distribution of the final protons follows directly from the differential cross section and is expressable in terms of two integrals $a^\pm$ and $c^\pm$ defined by:

$$a^\pm=\int\frac{u_0(R)}{R}\exp[i(\mathbf{K}\pm\tfrac{1}{2}\mathbf{k})\cdot\mathbf{R}]d\mathbf{R},$$
$$c^\pm=\int\frac{u_0(R)}{R}J(R)\exp[i(\mathbf{K}\pm\tfrac{1}{2}\mathbf{k})\cdot\mathbf{R}]d\mathbf{R}, \qquad (2)$$

where $\mathbf{K}$=momentum of a final proton in the center-of-mass system; $\mathbf{R}$=relative distance between the two nucleons; and $u_0(R)$=solution of the radial part of Schrödinger's equation for the *S*-state of the deuteron.

TABLE IV. Coefficients in expressions for total absorption cross section (see formula 4).

Theory	A	B	C
$S(S)$	1	0	-1
$PS(PV)$	$\frac{1}{3\mu^2}[E^2K^2-k^2]$	$\frac{E}{\mu^2}$	$\frac{1}{\mu^2}[E^2K^2+k^2]$
$V(V)$	$\frac{1}{3E^2}[E^2K^2-k^2]$	$\frac{1}{3E}$	$\frac{1}{3E^2}[E^2K^2+k^2]$
$PV(PV)$	1	0	$-\frac{1}{3}$

The angular distributions predicted by the four theories are listed in Table II. Curves for the angular distribution of the protons in the center-of-mass system at 22.7-Mev meson kinetic energy are given in Fig. 1. Table III lists $\sigma(0°):\sigma(45°):\sigma(90°)$ in the center-of-mass system for incident mesons whose kinetic energy is 5, 22.7, 50, and 100 Mev in the laboratory. Figure 2 shows the effect of the inclusion of the $^3D_1$ contribution to the ground state of the deuteron on the angular distributions in the c.m. system for the *PS*(*PV*) and *PV*(*PV*) theories. The effect on the total cross section for the processes $\pi^++d\rightleftarrows p+p$ is negligible. It is to be noted that at the lowest energy, the angular distributions for the *PS*, *V*, and *PV* theories are much more isotropic than the curve for the *S* theory. This can be understood in a qualitative way as follows: at the lowest energy, the π^+ meson is predominantly in an angular momentum state described by $l=0$. The states which may be occupied by two identical nucleons are limited in number by the Pauli principle and are $^1S_0$; $^3P_{2,1,0}$; $^1D_2$; etc. For *S*-state π^+ mesons, the final states of the two proton system to which transitions occur, are determined by conservation of total angular momentum and parity. They are, for the four theories, *S*—none; *PS*—$^3P_1$; *V*—$^3P_{2,1,0}$ and $^3F_2$; *PV*—$^1S_0$ and $^1D_2$.

Since the meson is assumed to be in an *S*-state initially, we would expect an isotropic distribution of protons in the center-of-mass system for *PS*, *V*, and *PV* mesons in the limit of zero energy since there is no reference axis defined by the initial state. On the other hand, a scalar π^+ meson in an *S*-state cannot be absorbed by the deuteron. (This was pointed out by Tamor, reference 1.) Any absorption of the scalar meson must take place from the $l>0$ states. This supplies for scalar mesons an initial state reference axis, and general arguments yield for the reaction,

$$\pi^+(l>0)+d\rightarrow 2p(^3P_{2,1,0}+{}^3F_{4,3,2}+\text{etc.}),$$

an angular distribution of the resultant protons which vanishes at 90° with respect to the incident π^+ meson beam; the fact that a scalar meson with $l=0$ cannot be absorbed by the deuteron is also responsible for the smaller cross sections recorded in Table V for the scalar case (see subsequently). These remarks explain qualitatively the curves at 5 Mev. At the higher energies, the deviations from isotropy in the case of *PS*, *V*, and *PV* mesons are due to the contributions from orbital angular momentum states with $l>0$. Therefore, the anisotropy should increase as the kinetic energy of the absorbed meson increases. In addition, the relatively large anisotropy of the *PS*(*PV*) and *V*(*V*) angular distribution shows that even for low energy mesons, the absorption of mesons from the *p*-state competes strongly with absorption from the *s*-state: this is due to the presence of gradient operators in the interaction for the $PS(PV)$ and $V(V)$ theories.

The total absorption cross section is evaluated using the relationship:

$$\sigma = (2\pi/v) \int \langle |M|^2 \rangle_{Av} d\mathbf{p}/dE_f, \qquad (3)$$

where v is the relative velocity of the π^+ meson and the deuteron and $d\mathbf{p}/dE_f$ = density of states per unit final energy $= \frac{1}{2} K d\Omega/(2\pi)^3$ (the direction of the incoming meson is chosen as the polar axis in $d\Omega$). The indicated integrations are straightforward and lead to

$$\sigma = \frac{2\pi g^2 N^2}{v} \frac{K}{E} \Bigg\{ A \Bigg[\frac{1}{\Gamma_1^+ \Gamma_1^-} + \frac{1}{\Gamma_2^+ \Gamma_2^-} + \frac{1}{kK(\Gamma_2 - \Gamma_1)} \ln \frac{\Gamma_1^- \Gamma_2^+}{\Gamma_1^+ \Gamma_2^-} \Bigg] + B \Bigg[\frac{\Gamma_1 + \Gamma_2}{kK(\Gamma_1 - \Gamma_2)} \ln \frac{\Gamma_1^+ \Gamma_2^-}{\Gamma_1^- \Gamma_2^+} \Bigg] + C \Bigg[\frac{1}{2kK\Gamma_1} \ln \frac{\Gamma_1^+}{\Gamma_1^-} + \frac{1}{2kK\Gamma_2} \ln \frac{\Gamma_2^+}{\Gamma_2^-} - \frac{1}{kK(\Gamma_1 + \Gamma_2)} \ln \frac{\Gamma_1^+ \Gamma_2^+}{\Gamma_1^- \Gamma_2^-} \Bigg] \Bigg\}, \qquad (4)$$

TABLE V. Total π^+ absorption cross section evaluated for four different incident π^+ kinetic energies (laboratory system). $\sigma/(g^2/\hbar c) \times 10^{-27}$ cm^2.

Theory \ π Kinetic energy (in Mev)	5	22.7	50	100
$S(S)$	1.5	2.0	2.2	1.9
$PS(PS)$[a]		6.9		
$PS(PV)$	20.6	9.6	7.1	4.4
$V(V)$	8.2	1.9	0.70	0.23
$PV(PV)$	58.6	19.4	9.8	6.0

[a] Absorption cross section for the $PS(PS)$ theory was only evaluated at 22.7 Mev for comparison with the reaction $P+P \rightarrow D+\pi^+$ at 340 Mev.

where

$$\begin{pmatrix} \Gamma_1 \\ \Gamma_2 \end{pmatrix} = \begin{pmatrix} \gamma^2 \\ \beta^2 \end{pmatrix} + K^2 + \tfrac{1}{4} k^2$$

$$\Gamma_i^\pm = \Gamma_i + Kk$$

and A, B, C, for the different theories are listed in Table IV. The numerical values for the absorption cross section for incident π^+ mesons of 5, 22.7, 50 and 100-Mev kinetic energy are listed in Table V.

Since the transition probability for the absorption of π^- mesons from the K-shell of the mesic-deuteron atom is finite in all cases except for the scalar field, the cross sections for the π^+ absorption should go as $1/v$ for small v, as indeed they do.[8]

TABLE VI. Observed angular distribution of π^+ mesons in the laboratory system produced in 340-Mev $p-p$ collisions. $\sigma \times 10^{28}$ cm^{-2} steradian.

Angle in laboratory (in degrees)	σ
0	2.0
18	1.63
30	0.58
60	<0.17

3. THE REACTION $p+p \rightarrow \pi^+ + d$

Experiments at Berkeley[9] indicate that in 340-Mev $p-p$ collisions, the cross section for the reaction $p+p \rightarrow \pi^+ + d$ is comparable to the cross section for the reaction $p+p \rightarrow \pi^+ + n + p$. Table VI lists the total cross section of these two reactions at four different angles. The contribution to the production cross section of the first reaction can be predicted theoretically on the basis of Tables II and IV, using detailed balancing arguments. The total production cross section may be obtained from the absorption cross section using the relationship:

$$\sigma^{\text{prod}} = \tfrac{3}{2}(2S+1)(k^2/K^2)\sigma^{\text{abs}},$$

where S is the spin of the π^+-meson, k is the momentum of the meson in the c.m. system, and K is the momentum of the proton in the c.m. system. Table VII lists the total cross sections for the reaction $p+p \rightarrow \pi^+ + d$ for incident proton energies in the laboratory system corresponding to the four meson energies used in the computations of Sec. 2. The ratios $\sigma^{\text{abs}}/\sigma^{\text{prod}}$ are also recorded in this table for $S=0$; for $S=1$, every ratio is reduced by a factor of 3. Thus the spin of the charged π meson will be uniquely determined[10] when the pro-

TABLE VII. Total π^+ production cross section evaluated for $p-p$ collisions at four different energies. $\sigma^{\text{prod}}/(g^2/\hbar c) \times 10^{-28}$ cm^2.

Proton kinetic energy (Mev)	302	340	394	494
Meson kinetic energy (Mev)	5	22.7	50	100
$\sigma^{\text{abs}}/\sigma^{\text{prod}}$	95.4	18.0	8.9	5.1
Theory				
$S(S)$	0.15	1.1	2.4	2.8
$PS(PS)$		3.8		
$PS(PV)$	2.2	5.3	7.9	8.6
$V(V)$	0.85	1.1	0.75	0.47
$PV(PV)$	6.1	10.8	11.2	11.8

[8] It should be remembered that the correct cross sections at very low energy would behave quite differently because of the coulomb barrier of the deuteron.

[9] Cartwright and Richman (private communication).

[10] It seems to us that this method provides a much more clearcut method for determining the meson spin than the Wentzel experiment (see G. Wentzel, Phys. Rev. **75**, 1810 (1949)). Dr. M. H. Johnson has informed us that he independently suggested the measurement of the cross sections for the two reactions $\pi^+ + d \leftrightarrows p + p$ as a means of determining the meson spin.

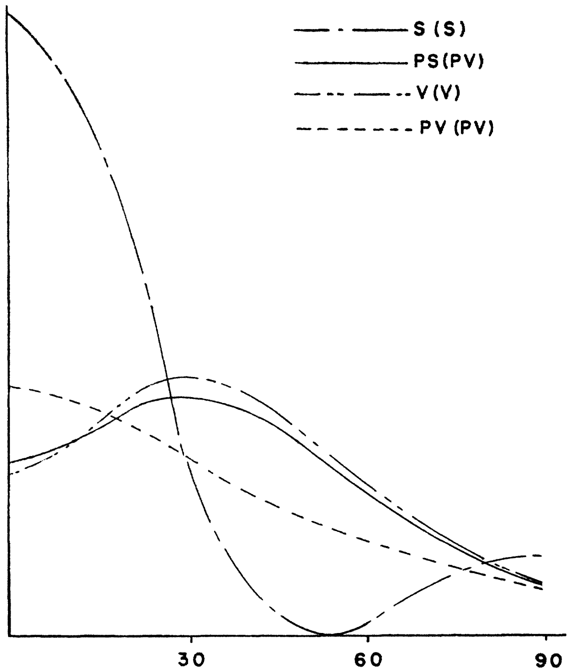

FIG. 3. Angular distribution of π^+ mesons in the laboratory at 340 Mev for the reaction $p+p\rightarrow\pi^++d$. Same remarks apply here as for Fig. 1.

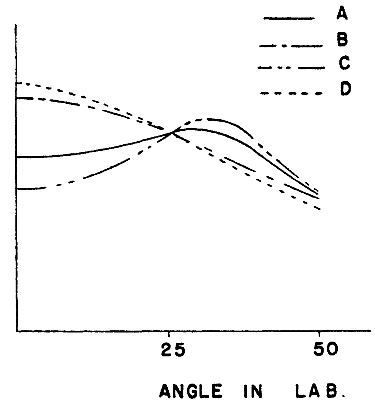

FIG. 4. Angular distribution of π^+ mesons in the laboratory at 340 Mev for the reaction $p+p\rightarrow\pi^++d$. Same remarks apply here as for Fig. 2.

duction and absorption cross sections are known within a factor of three (unless, of course, the spin is greater than 1 in which case the accuracy will have to be better). Once the spin of the charged meson is known, the parity is automatically determined by the results of the π^- meson absorption in deuterium referred to previously. The angular distribution of the π^+ mesons in the c.m. system is the same as the protons but the kinematics changes the laboratory distribution: the results for 340-Mev protons in the laboratory system are given in Figs. 3 and 4.[11] When the data in Table VI are analyzed as to the relative contributions of the two competing reactions, it is hoped that it will be possible to determine the nature of the charged π-meson. If we consider just the two meson theories which are compatible with the π^-(K shell)$+d$ reactions, reference to Fig. 4 shows that the $PV(PV)$ theory predicts a slightly more isotropic distribution of π^+ mesons in the laboratory than does the $PS(PV)$ theory in the reaction $p+p\rightarrow\pi^++d$. However, a more feasible method of deciding between the PS and PV theories is suggested by Tables V and VII. The absorption cross section for the PS theory is essentially constant in the meson energy range of 5 to 100 Mev, whereas the PV theory predicts a decrease of a factor ten. This has as a consequence that the production cross section increases by a factor of ten for the PS theory in the energy region 300 to 500 Mev whereas the PV production cross section remains essentially constant. Either effect can be checked experimentally and the results could offer another—albeit less conclusive—method for determining whether the charged π-meson is pseudoscalar or pseudovector.

[11] The angular distributions for the reaction $\pi^++d\rightarrow p+p$ were given only in the c.m. system since the transformation to the system in which the deuteron is at rest only changes the distributions slightly for 22.7-Mev mesons.

4. ACKNOWLEDGMENTS

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