## Title

ON THE ANGULAR DISTRIBUTION AND THE POLARIZATION OF THE DEUTERON IN THE REACTION P t P-*D t it1""

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# ON THE ANGULAR DISTRIBUTION AND THE POLARIZATION OF THE DEUTERON IN THE REACTION $P + P \rightarrow D + \pi^+$

K. M. Watson and C. Richman

July 12, 1951

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Cross sections at several angles for the reaction $P + P \rightarrow \pi^+ + D$ have been measured[1,2,3]. For energies not too far above threshold (i.e., for those at which the cross sections have been measured) and in the center-of-mass frame of reference there is reason to believe[4,5] that only orbital S- and P-states of the meson with respect to the deuteron contribute appreciably to the cross section.

There will be no S- and P-wave interference in the differential cross section, so for the moment we can restrict our considerations to just the contribution from meson P-waves. Combining the intrinsic angular momentum of the deuteron with the P-wave orbital motion, we obtain a total angular momentum $j = 0, 2$ ($j = 1$ is forbidden by parity considerations[5] if the meson is assumed to be pseudoscalar, in accord with present evidence). These values of $j$ arise from the ${}^1S_0$ and ${}^1D_2$ states, respectively, of the initial p-p system.

The wave functions for the orbital motion of the meson will then be described by the spherical harmonics $Y_1^{\mu}(\theta, \phi)$

(with the polar axis defined by the proton beam direction) and those of the internal coordinates of the deuteron by $\Sigma_1^{\mu}$ ($\mu$=1, 0, -1). Then the linear combinations of these, $Q_0$ and $Q_2^0$, which transform as a scalar and as the spherical harmonic $\mathcal{Y}_2^0$ will arise from the $^1S_0$ and $^1D_2$ states, respectively, of the initial p-p system.

The asymptotic form of the outgoing wave will be proportional to

$$\frac{e^{iqr}}{r}\left[Q_0 + \eta\, Q_2^0\right] , \qquad (1)$$

where q is the meson momentum and $\eta$ is a parameter. Writing $\eta = \varepsilon\, e^{i\sigma}$, the resulting angular distribution of the mesons will be

$$F(\theta) = 1 + \frac{\varepsilon^2}{2} + \sqrt{2}\,\varepsilon\cos\sigma + 3\cos^2\theta\left(\frac{\varepsilon^2}{2} - \sqrt{2}\,\varepsilon\cos\sigma\right) \qquad (2)$$

Including an arbitrary amount of contribution to the cross section from mesons in S-states, we arrive at the following generalization of the cross section given previously[4]:

$$d\sigma = \sigma_0 \frac{d\Omega}{4\pi}\left[1 + a\frac{q^2}{\mu^2 c^2}\, F(\theta)\right] , \qquad (3)$$

where F(θ) is given by Eq. (2) and $\mu$ is the mass of the meson.

Near threshold it is assumed that a is a constant and that $\sigma_0$ is just q (from the phase space factor) times a constant.

Integrating, we obtain the total cross section

$$\sigma = \sigma_0 \left[1 + a(1+\varepsilon^2)\frac{q^2}{\mu^2 c^2}\right] , \qquad (4)$$

which is of the specific form given previously[4], with $a(1+\varepsilon^2) \equiv b$. We see that $\varepsilon^2$ represents the relative amounts of ${}^1S_0$ and ${}^1D_2$ contribution of the initial p-p system to the P-wave partial cross section.

The approximate value, $b = 8$, was deduced earlier[4]. This value is consistent with the observed angular distribution[3], which however implies that b cannot be much less than 8. From the experimental cross sections[3], it would then follow that at 340 Mev $\sigma_0 \simeq 5(10)^{-29}$ cm$^2$. The observed angular distributions are consistent with a pure $\cos^2 \theta$ dependence from the meson P-states, which would imply $\cos \sigma = -1$, $\varepsilon^2 = 2$ (the quoted experimental errors imply that these relations are also quite approximate). Of more positive significance is the conclusion from the observed angular asymmetry that the large contribution from the ${}^1D_2$ state of the initial protons implies, independently of a specific model, that non-central interactions are involved[6] (since the deuteron is mostly in an S-state).

Eq. (1) suggests that the deuterons observed at an angle $(\Theta, \Phi)$ may be polarized[7]. Indeed, the direction of the polarization is given by the average values of the components of intrinsic angular momentum of the deuteron, which are $J_x = - R \sin \Phi$, $J_y = R \cos \Phi$, $J_z = 0$ (i.e., at right angles to the plane defined by the direction of the protons and the deuterons).

The degree of polarization (considering just the P-wave component of the cross section), $R'$ $(0 < R' < 1)$, is given by the numerical magnitude of

$$R = 3\sqrt{2}\ \varepsilon \sin \sigma \cos \Theta \sin \Theta \left[ F(\Theta) \right]^{-1}, \tag{5}$$

where $F$ is given by Eq. (2). R vanishes for a pure $\cos^2 \theta$ angular distribution.

The detection of this polarization, if non-vanishing, would appear feasible. The beam of deuterons produced is more intense than the accompanying meson beam[8], which has been used to study meson scattering[9]. A possible means of detection would be by means of (d, p) scattering, the polarization effects of which have been used by Wouters[10] to measure polarization in (n, p) scattering.

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