## The Reaction $p+p\rightarrow\pi^{+}+d$ with Polarized Protons*†

F. S. CRAWFORD, JR., AND M. L. STEVENSON
*Radiation Laboratory, University of California, Berkeley, California*

(Received June 21, 1954)

MARSHAK and Messiah[1] have pointed out that if mesons are present in both $S$ and $P$ states in the reaction $p+p\rightarrow\pi^{+}+d$, then it is possible to obtain, through interference, a large azimuthal asymmetry in the angular distribution, provided that a polarized proton beam (or target) is used. If a substantial amount of such an asymmetry is indeed observed, then the relative amounts and phases of $S$ and $P$ waves can be estimated. De Carvalho *et al.*[2] looked for an asymmetry in meson production in the course of examining possible asymmetric background in the scattering from hydrogen of 439-Mev polarized protons. They obtained a null result of asym $=-0.07\pm0.085$.

Following the Rochester technique,[3] Chamberlain and co-workers[4] have obtained an external beam of 315-Mev protons from the Berkeley cyclotron having a polarization[5] estimated to be $|P|=|2\langle S_y\rangle|=0.73$. With this beam, we have made measurements of the left-right asymmetry of meson production in the plane perpendicular to the proton polarization, using coincidence detection of the meson and deuteron, and a liquid hydrogen target. Measurements were made at incident proton energies of 317 and 310 Mev. The results of the raw data are $(R-L)/(R+L)=0.16\pm0.03$ and $0.23\pm0.04$ at 317 and 310 Mev, respectively. $R$ and $L$ refer to the direction of the produced meson, as seen by the incident proton. (The polarized proton beam is produced by a "left" scatter.[4])

In the notation of Marshak and Messiah, $(R-L)/(R+L)=PQ(A\sin\theta)/(A+\cos^2\theta)$. Here, $A+\cos^2\theta$ is the angular dependence of the differential cross section in the c.m. system for unpolarized protons, and $Q$ is the interesting quantity, involving the relative amplitudes and phases of the transitions involved. It is apparent that the angular factor becomes unity, independent of $A$, at $\theta=90°$. However, measurements were made at 69° because of meson energy loss in the target. We used $A=0.40$ and 0.49[6] at 317 and 310 Mev, respectively, to average the angular factor. With $|P|=0.73$ this gives $|Q|=0.37\pm0.06$ and $0.42\pm0.07$ at 317 and 310 Mev, respectively, Analysis[7] of the excitation function shows that $Q$ is expected to vary by less than ten percent between 310 and 317 Mev, so that we may conveniently combine these data to obtain an average $|Q|=0.39\pm0.05$ at an average proton energy of 314 Mev. $(\text{K.E.}_{\pi})_{\text{c.m.}}=11.3$ Mev.

We satisfied ourselves as to the following points: uniformity of counter sensitivity, insensitivity of counters to stray fields, target and counter alignment, exclusion of $p+p\rightarrow\pi^{+}+p+n$, and reproducibility during many interchanges of counter positions. As an over-all check, the experiment was repeated using the ordinary "scattered" beam, which has been shown[4] to be unpolarized. The beam energy was degraded with a Be absorber to correspond to the measured energy of the polarized beam. At 317 and 310 Mev, $(R-L)/(R+L)=-0.02\pm0.06$ and $0.04\pm0.04$ were obtained, respectively. These results have convinced us that no hidden asymmetries were present in the equipment. The average of the left and right measurements with the polarized beam agreed with the results obtained with the unpolarized beam, and with our previous measurements.[6]

Rosenfeld[7] has compiled data on pion production from nucleons and compared it with the phenomenological theory of Watson and Brueckner.[8] In his notation, $Q=\sqrt{2}\eta_c\eta(\eta^2+\eta_c^2)^{-1}\sin(\psi-\tau_1)$, where $\eta=p_\pi/m_\pi c$, and $\eta_c$ is obtained by fitting the 90° (c.m.) excitation function data to $4\pi d\sigma_{10}(90°)/d\Omega=\alpha_{10}(\eta+\eta^3\eta_c^{-2})$. The terms in $\eta$ and $\eta^3$ come from $S$ and $P$ mesons, respectively. $S_0/S_2+\sqrt{\tfrac{1}{2}}=|S_0/S_2+\sqrt{\tfrac{1}{2}}|\exp(i\psi)$, and $S_1/S_2=|S_1/S_2|\exp(i\tau_1)$, where $S_0$ and $S_2$ are the complex transition amplitudes giving $P$-state meson production from ${}^1S_0$ and ${}^1D_2$ protons, respectively, and $S_1$ is the amplitude for $S$-state meson production from ${}^3P_1$ protons. Our data[6] yields $\eta_c=0.62\pm0.16$. With the measured $Q$, at $\eta=0.41$, this gives $|\sin(\psi-\tau_1)|=0.61\pm0.10$.

The authors wish to thank Dr. Hugh Bradner, Mr. Robert E. Donaldson, Dr. Myron L. Good, Mr. H. Brook Knowles, Mr. R. Tripp, and Mr. T. Ypsilantis for assistance during the measurements.

* This work has been performed under the auspices of the U. S. Atomic Energy Commission.
† This work was reported as a post-deadline paper at the Minneapolis meeting of the American Physical Society, June 28–30, 1954 [Bull. Am. Phys. Soc. 29, No. 5 (1954)].

1 R. E. Marshak and A. M. L. Messiah, Nuovo cimento **11**, 337 (1954).
2 De Carvalho, Heiberg, Marshall, and Marshall, Phys. Rev. **94**, 1796 (1954).
3 Oxley, Cartwright, Rouvina, Baskir, Klein, King, and Skillman, Phys. Rev. **91**, 419 (1953).
4 Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. **93**, 1430 (1954).
5 Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. (to be published).
6 F. S. Crawford, Jr., and M. L. Stevenson, University of California Radiation Laboratory Reports UCRL 2187, UCRL 2188 (unpublished) and work to be published.
7 A. H. Rosenfeld, Phys. Rev. (to be published).
8 K. M. Watson and K. A. Brueckner, Phys. Rev. **83**, 1 (1951).

## Regularity in Magnetic Moments of Odd Nuclei*

MORRIS F. SCHARFF†
*Department of Physics, University of Chicago, Chicago, Illinois*

(Received June 28, 1954)

WANGSNESS[1] and de-Shalit[2] have observed a regularity between the magnetic moment of an