SIGNIFICANCE OF NEUTRON-PROTON POLARIZATION MEASUREMENTS IN THE 20-Mev ENERGY RANGE*

M. H. Hull, Jr., F. A. McDonald, H. M. Ruppel, and G. Breit
Department of Physics, Yale University, New Haven, Connecticut
(Received December 26, 1961)

The determination[1] of the T = 0 phase parameters from n-p scattering data has been less nearly unique than that[2,3] of the parameters for T = 1 from p-p scattering. The data in the preceding note[4] suggest that fits YLAN3M and YLAN3, for which there was a preference for statistical reasons[1] as well as plausibility regarding fitting by means of meson theory,[1,5] are indeed the more probable. The new data[4] supply information concerning the T = 1 phase parameters and, assuming the more probable type of fit YLAM, the data suggest a modification of the phase-parameter dependence on energy at low energies.

The new data are compared with n-p fits YLAN0, YLAN2M, and YLAN3M in Figs. 1 and 2 at energies of 16 and 24 Mev, respectively. The effect of the difference between the energies 16.4 and 23.7 Mev and the values 16 and 24 Mev used in the calculations is negligible for purposes of this comparison. Fits YLAN1 and YLAN2 give graphs falling between those for YLAN0 and YLAN2M at higher angles and behaving similarly to YLAN0 and 2M at the smaller angles. Fit YLAN3 gives values of P very closely similar to those for YLAN3M. These fits are distinguished from YLAN0, 1, 2, 2M by the single nearly symmetrical arch-like plot. The data suggest the YLAN3M type of angle dependence in preference to that for YLAN0, 1, 2, 2M.

It was found that the large polarization expected for YLAN3M with the original T = 1 values from YLAM was caused mainly by cross terms between amplitude contributions from $^3S_1+{}^3D_1$ and ^3P states. Since the $^3S_1+{}^3D_1$ parameter $^3\theta S_1$ is well defined by the binding energy of the deuteron and the scattering of thermal neutrons by protons, a readjustment of ^3P states was needed in order to reduce the theoretical values of the polarization $P_{n\text{-}p}$.

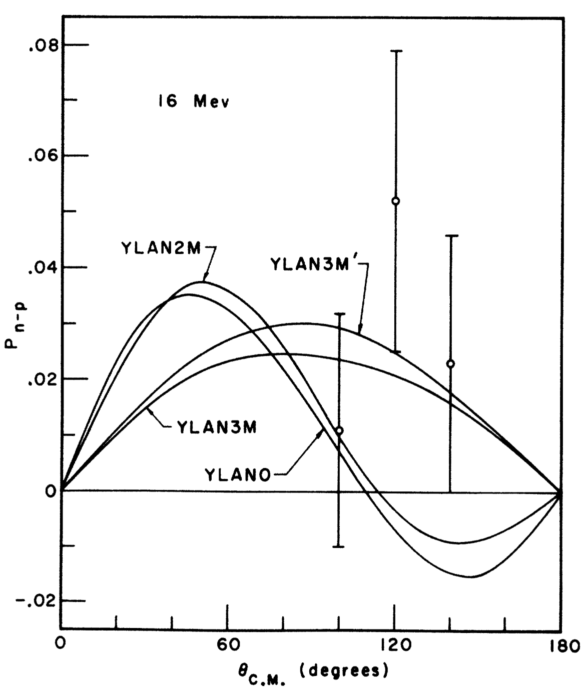

FIG. 1. Comparison of computed and observed n-p polarizations at 16 Mev.

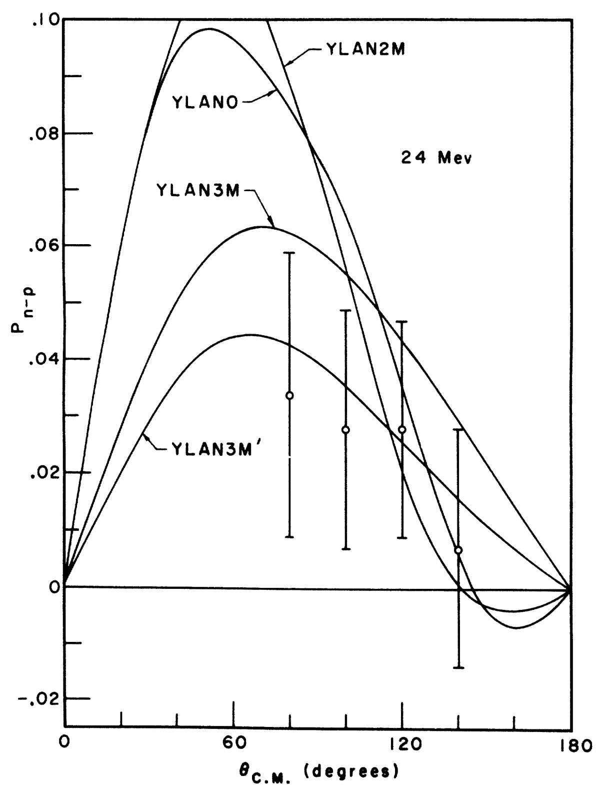

FIG. 2. Comparison of computed and observed n-p polarizations at 24 Mev.

The need for a readjustment is not surprising because of the paucity of p-p polarization data at the lower energies available for previous analyses.[2,3] Below 66 Mev there was[6] in existence only the qualitative point at 16.0 Mev at energies above those of the difficult experiments at 3.3 Mev. Since the combinations of parameters which determine p-p polarization enter the calculation of n-p polarization, disagreement of the new experiments with the combined employment of YLAM and YLAN3M is only natural. The YLAM values of the ^3P phase shifts were represented as a sum of contributions such as would arise from the action of a central potential and first order effects of spin-orbit and tensor interaction terms, and the spin-orbit part was adjusted in the ratio suggested by comparison with the new n-p polarization data. On joining the new ^3P values to those at 66 Mev there was obtained a first approximation $(\mathrm{YLAM})_1'$ to the revised fit (YLAM)′. Gradient searches were performed with $(\mathrm{YLAM})_1'$ as a starting point. Singlet even phase shifts K_0, K_2 were readjusted first, employing all data previously used for YLAM up to and including those at 68.3 Mev. The correction function was peaked at 30 Mev. Its small residue at 68.3 Mev was removed by graphical smoothing. The parameters $^3\delta P_0$ and $^3\theta F_2$ were then released from their YLAM values and $^3\delta P_1$, $^3\theta P_2$, and ρ_2 were also searched in the final adjustment. The final mean square error,[2] D, for p-p data in the energy range 9.69-68.3 Mev is 0.94 for (YLAM)′ while for YLAM the corresponding number is 0.84. At 24 Mev $^3\delta P_0$, $^3\delta P_1$, $^3\theta P_2$, ρ_2, and $^3\theta F_2$ are changed by the readjustment from their YLAM values (0.1830, -0.1060, 0.0470; -0.0382, 0.0009) to the YLAM′ values (0.2115, -0.1060, 0.0414; -0.0368, 0.0015), respectively. At 16 Mev the change is similarly from (0.1421, -0.0776, 0.0264; -0.0230, 0.0002) for YLAM to (0.1267, -0.0776, 0.0241; -0.0221, 0.0009) for YLAM′. The values of the δ and θ are in radians and the notation is as explained in reference 2.

The modified phase parameters have been compared with those for YLAM, YRB1, and the Yale potential[7] over the energy range 0-180 Mev. The changes from YLAM are small except for the $^3P_0$ state and usually agree more nearly with YLAM than with YRB1 or the Yale potential, and the changes are within the published uncertainties[2] of YLAM. An exception takes place in the case of the $^3F_2$ state. At the lowest energies the revised θF_2 agrees better with the Yale potential than with YLAM or YRB1. Graphical comparison of YLAM′ and YLAM shows nearly equally good fits to cross section at 25.63 and 39.4 Mev. The cross section at 9.69 Mev is represented better by the older fit YLAM at scattering angles between 42° and 85°, (YLAM)′ being too low at these angles. On the other hand, for the two points at $\theta = 86°$ and 90° the difference is practically within the data errors. In the interference minimum between 30° and 40° there is a slight preference for (YLAM)′.

The ratio of the values of P_{n-p} for the modified fit (YLAN3M)′ to the original YLAN3M at the experimental angles is on the average 0.6 at 24 Mev and 1.2 at 16 Mev. The former has to do with a more definite effect and indicates through (YLAM)′ a smaller triplet-odd spin-orbit interaction at 24 Mev than previously considered. It speaks in favor of a large mass of the hypothetical vector meson which may be responsible for the spin-orbit interaction and has been correlated with the repulsive core and electromagnetic form factors.[8] As will be discussed elsewhere, this fits in qualitatively with the recent finding of a $T=0$, $J=1^-$ neutral vector meson[9] with a mass of about $\simeq 5.7$ pion masses.

The employment of $T=1$ phase parameters determined from p-p scattering in the analysis of n-p scattering data assumes the validity of charge independence. Since a large part of P_{n-p} is caused by the same combinations of differences in the ^3P phase parameters which are responsible for P_{p-p}, further experimental and theoretical work in the general energy range of the new measurements[4] should provide a specific test of charge independence concerned especially with spin-orbit-like interactions in ^3P states.

Within the present experimental accuracy the effects of magnetic scattering[10] are negligible. At 24 Mev for P_{n-p} the correction caused by the interaction of the magnetic moment of the neutron with the magnetic field caused by the motion of the proton's charge computed on the basis of (YLAN3M)′ is -4.4 %, -3.7 %, -3.4 %, -3.3 % of P_{n-p} at center-of-mass scattering angles of 80°, 100°, 120°, 140°, respectively. In view of the uncertainties in the magnetic effects caused by wave function distortion,[11] their relative smallness is convenient for the employment of p-p phase-parameter values in n-p phase analysis such as discussed above.

New unpublished data[12] on P_{p-p} in the energy range 27 to 97 Mev indicate smaller polarization than data used in arriving at YLAM and are in qualitative agreement with the conclusions reached above.

*This research was supported by the U. S. Atomic Energy Commission and by the U. S. Army Research Office (Durham).

[1]M. H. Hull, Jr., K. E. Lassila, H. M. Ruppel, F. A. McDonald, and G. Breit, Phys. Rev. 122, 1606 (1961).
[2]G. Breit, M. H. Hull, Jr., K. E. Lassila, and K. D. Pyatt, Jr., Phys. Rev. 120, 2227 (1960).
[3]H. P. Stapp, M. J. Moravcsik, and H. P. Noyes, Proceedings of the 1960 Annual International High-Energy Conference at Rochester (Interscience Publishers, Inc., New York, 1960), p. 128.
[4]W. Benenson, R. L. Walter, and T. H. May, preceding Letter [Phys. Rev. Letters 8, 66 (1962)].
[5]G. Breit, K. E. Lassila, H. M. Ruppel, and M. H. Hull, Jr., Phys. Rev. Letters 6, 138 (1961).
[6]W. A. Blanpied, Phys. Rev. 116, 738 (1959).
[7]K. E. Lassila, M. H. Hull, Jr., H. M. Ruppel, F. A. McDonald, and G. Breit, Phys. Rev. (to be published).
[8]G. Breit, Phys. Rev. 51, 248 (1937); 51, 778 (1937); 53, 153 (1938). Y. Nambu, Phys. Rev. 106, 1366 (1957); J. Sakurai, Ann. Phys. 11, 1 (1960). G. Breit, Proc. Natl. Acad. Sci. U. S. 46, 746 (1960); Phys. Rev. 120, 287 (1960).
[9]B. C. Maglić, L. W. Alvarez, A. H. Rosenfeld, and M. L. Stevenson, Phys. Rev. Letters 7, 178 (1961); A. Pevsner, R. Kraemer, M. Nussbaum, P. Schlein, T. Toohig, M. Block, A. Kovacs, and C. Meltzer, Aix en Provence Conference, 1961 (unpublished).
[10]A. Garren, Phys. Rev. 96, 1709 (1954); 101, 419 (1956).
[11]G. Breit, Phys. Rev. 99, 1581 (1955); 106, 314 (1957).
[12]The authors are indebted to Mr. Peter Christmas of the National Physical Laboratory for supplying them with his preliminary results and for permission to quote their qualitative implication.

NEUTRAL PION PRODUCTION BY 960-Mev NEGATIVE PIONS*

A. Weinberg,† A. E. Brenner, and K. Strauch
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts
(Received December 28, 1961)

Using a 1.14-Bev/c π^- beam from the Brookhaven Cosmotron, we are studying neutral pion production in the reactions

$$\pi^- + p \to \pi^0 + n, \qquad (A)$$

$$\to 2\pi^0 + n, \qquad (B)$$

$$\to 3\pi^0 + n. \qquad (C)$$

We report here on the differential cross section of the elastic charge exchange reaction (A) based on the study of bubble chamber pictures containing 1.01×10^5 incident pions. Integral cross-section ratios for the reactions (A), (B), and (C) are also given. Differential cross sections for reaction (A) are necessary in order to analyze the $T=\frac{1}{2}$ pion-nucleon interaction. No such information has been available heretofore above 500 Mev.

The 15-inch diameter, 14-inch deep bubble chamber[1] located in a 19.5-kilogauss field is filled with a mixture of propane, ethane, and methyl iodide containing 0.061 g/cm^3 of H, 0.252 g/cm^3 of C, and 0.948 g/cm^3 of I. Under operating conditions the radiation length is 8.1 cm. At the entrance of the fiducial volume, the π^- beam has an energy of 990 ± 15 Mev (as determined by wire measurements), and events are accepted in an energy interval of 60 Mev. This places the present study on the high-energy side of the 900-Mev pion-nucleon resonance.

The film is scanned for events in which two or more electron pairs point to a π^- interaction with no visible secondaries (zero-prong endings). These two-pair events come from: (1) reaction (A) in free hydrogen, (2) $2\pi^0$ production in H, C, and I, in which only 2 gammas materialize in the chamber,[2] and (3) $1\pi^0$ production in C and I. Using the methods of analysis[3] to be described, we believe that it is possible to obtain a sample of events corresponding to reaction (A) which contains only a small contamination from the background (2) and (3).

The sample of two-pair events used to obtain the angular distribution of reaction (A) is limited to events in the interval $50°\leq\bar{\phi}\leq90°$, where $\bar{\phi}$ is the angle between one of the π^0-decay gamma rays in the π^0 rest system and the π^0-flight direction. The two main advantages of this selection are:

(a) Since the energy of each gamma ray is unknown, there are two possible solutions for the direction of flight of the parent π^0. However, the bisector of the angle between the two decay gamma rays is a good approximation to the original π^0 direction. In the pion-nucleon center-of-mass system, a typical difference between either of the two possible solutions and the bisector direction is ±4°, the maximum difference being ±12°.

(b) The contamination from background events (2) and (3) is small. This is because at a given