DETERMINATION OF ρ, γ, π COUPLING CONSTANT FROM π^+ PHOTOPRODUCTION*

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Recently McKinley[1] has calculated the photoproduction cross sections with the inclusion of the contribution of the ρ-meson interaction, and Baum, Robinson, and Criegee[2] have obtained a set of experimental data on π^+ photoproduction from hydrogen in which emphasis has been placed on avoiding systematic errors. We have combined these two sets of results to determine the ρ, γ, π coupling constant Λ.

Using a 272.6-MeV x-ray beam from the University of Illinois 300-MeV betatron, Baum, Robinson, and Criegee measured relative differential cross sections for photoproduction of 42.4-MeV (lab) π^+ mesons from hydrogen at twelve laboratory angles from 50° to 170°. The laboratory energy of the pion was held constant in order to avoid variation in the energy-dependent factors and corrections entering into the determination of the pion flux. Each point has a statistical accuracy of about 1%. The π^+ mesons were produced in a 2-in. diameter liquid hydrogen target and were momentum-selected by an analyzing magnet and detected by a telescope of three thin plastic scintillators. The momentum bin was determined by floating-wire measurements and had a width of about 11%. Empty-target counting rates were 3% to 10%. Corrections to the data were made for counts due to large-angle pair positrons (maximum correction about 2% at 50° lab), positrons from π^0 mesons (about 3% at 50° lab, 0.7% at 150° lab), and π-μ-e decay (maximum variation with angle 5% of counting rate). The integrated-over-angle Bethe-Heitler bremsstrahlung spectrum was used to obtain cross-section values.[3] The center of the photon energy bin varied from 195 MeV at 50° to 253 MeV at 170°. Possible systematic errors from all sources in the relative cross sections are believed not to exceed 3%.

The theoretical cross sections incorporating the contribution of the ρ meson were calculated on Illiac, the digital computer of the University of Illinois, using the photoproduction amplitudes derived by McKinley. These amplitudes were derived by comparison of the dispersion relations for photoproduction to the dispersion relations for pion-nucleon scattering, following Chew, Goldberger, Low, and Nambu (CGLN).[4] These amplitudes differ from the photoproduction amplitudes used by other authors in the following points: A nonconstant real comparison function was introduced into the relationship between the resonant (3, 3) scattering amplitude and the corresponding photoproduction amplitude, to allow each amplitude to satisfy its own exact (fully relativistic) dispersion relation. This comparison function has the effect of multiplying the (3, 3) phase-shift amplitude h_{33}, when it appears in the CGLN combined scattering amplitudes $h^{(-+)}$, $h^{(+-)}$, $h^{(--)}$, and $h^{(++)}$, by a factor which equals 0.91 within 1% over the energy range of this experiment. The experimental s- and p-wave scattering phase shifts were represented by improved interpolative polynomials. Two different sets of polynomials were used: Set X which attempted to incorporate all experimental phase shifts at all energies, and Set Y which excluded experiments at 98, 150, and 170 MeV which do not appear to follow the trend of other experiments. Set X, which is the principal set used below, is given by the following expressions:

$$(\tan\delta_1)/q = 0.17 - 0.04\,q^2 + 0.01\,q^4,$$

$$(\tan\delta_3)/q = -0.1 - 0.036\,q^2 + 0.003\,q^4,$$

$$(\tan\delta_{11})/q^3 = -0.015 + 0.005\,q^2,$$

$$(\tan\delta_{13})/q^3 = -0.0035,$$

$$\omega(\tan\delta_{31})/q^3 = -0.13 + 0.072\,\omega - 0.012\,\omega^2,$$

$$q^3 \cot\delta_{33} = 4.108 + 0.7987\,q^2 - 0.8337\,q^4,$$

where q is meson momentum and ω is the system total energy less nucleon mass. q and ω are in units of the meson mass.

The contribution of the ρ meson was included using the amplitude of De Tollis, Ferrari, and Munczek.[5] This contribution to the isoscalar part of the amplitude introduces two new parameters: the squared mass of the ρ meson t_γ, and a constant Λ. Λ is the dimensionless coupling constant for the ρ, γ, π vertex introduced by Wong[6] and by Gourdin and Martin,[7] measured in units of the electronic charge e. For an explicit definition of Λ, see Eq. (10) in the paper of Gourdin, Lurié, and Martin.[8] In reference 5 the strength of the ρ, N, N vertex is determined from the nucleon electromagnetic form factors.[9] The value 22.4 times the squared mass of the pion[9] was taken for t_γ, and Λ was considered as a free parameter to be determined from this experiment.

The effect of choice of phase shifts upon the theoretical cross section is shown in Fig. 1. The upper two curves were calculated from the amplitudes of McKinley using phase-shift Sets X and Y, respectively, and with $f^2 = 0.08$, but with $\Lambda = 0$ so that the ρ-meson effect was not included. The lower two curves marked CGLN, 2.08 and CGLN, 2.18 were computed from the amplitudes of Chew, Goldberger, Low, and Nambu,[4] using the effective range formulas for the ρ-wave phase shifts as specified by Robinson,[10] with $f^2 = 0.081$, and with $\omega_0{}^* = 2.08$ and 2.18, respectively. The shape of the curves is not very sensitive to the value of f^2. The spread between these curves was taken to represent the uncertainty in the theory, arising principally from the uncertainty in the phase shifts. Also shown in Fig. 1 are the 12 experimental points, which are normalized to the CGLN, 2.08 curve at 63.6°. All of the curves disagree violently with the experimental points.

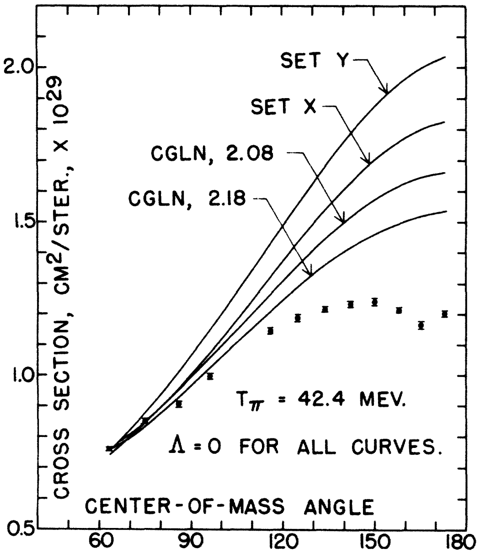

FIG. 1. Differential cross sections vs c.m. angle for 42.4-MeV mesons, with no ρ-meson contribution. The points are the data of this experiment. Only the statistical errors are shown. The experimental points are normalized at 63.6° to the curve CGLN, 2.08. The curves are calculated as follows: CGLN, 2.08 from the theory of Chew et al. as calculated by Robinson, with $f^2 = 0.081$, and $\omega_0{}^* = 2.08$; CGLN, 2.18 the same except $\omega_0{}^* = 2.18$; Set X and Set Y from the theory of McKinley with phase-shift Sets X and Y, respectively, $N^{(-)} = 0$, incorporating the comparison function, and with no contribution from multipion resonances.

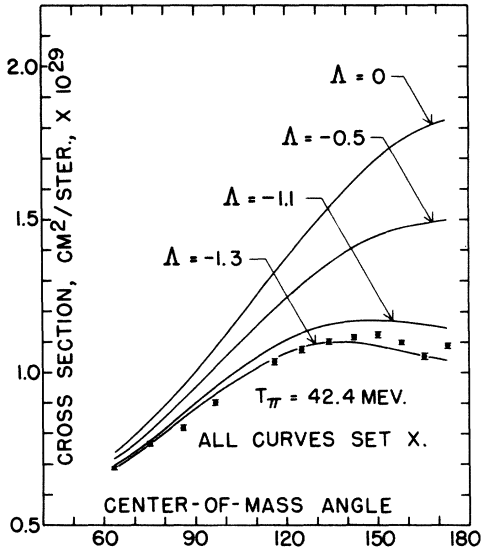

FIG. 2. Effect of ρ-meson interaction on photoproduction cross sections for 42.4-MeV mesons. The points are the data of this experiment. Only the statistical errors are shown. The experimental points are normalized at 63.6° to the curve $\Lambda = -1.3$. The curves are calculated from the theory of McKinley, with $f^2 = 0.08$, phase-shift Set X, $N^{(-)} = 0$, incorporating the comparison function, and for the values of Λ shown on the curves.

Theoretical curves including the ρ-meson contribution are shown in Fig. 2, along with the experimental points. These curves were calculated using phase shift Set X, but with various negative values for Λ as indicated. The experimental points are normalized to the $\Lambda = -1.3$ curve at 63.6°. The effect of the ρ meson appears mainly at large angles, where negative values of Λ cause a decrease in the cross section and bring it into very good agreement with experiment for $\Lambda = -1.3 \pm 0.1$. This effect is considerably greater than the effects of either the comparison function or choice of phase shifts. Taking into account the uncertainty in the $\Lambda = 0$ curve due to phase shifts, as illustrated in Fig. 1, we conclude that $\Lambda = -1.2 \pm 0.4$. If the latest ρ-meson mass[11] from pion beam experiments, $t_\gamma = 29\,\mu^2$, is used instead of $22.4\,\mu^2$, we obtain essentially the same good agreement with experiment for $\Lambda = -1.5 \pm 0.5$ (allowing for the uncertainty in the phase shifts). Other π^+ photoproduction experiments[12] have also indicated the need for inclusion of multipion effects, in that the experimental cross sections at large angles were smaller than predicted by CGLN amplitudes with any choice of phase shifts.

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[3] We are indebted to H. W. Koch and R. A. Schrack of the National Bureau of Standards for helpful discussions of bremsstrahlung and for computation of a number of tables of spectra.

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PRODUCTION OF ANTI-ISOBAR, ISOBAR PAIRS IN $\bar{p}$-p COLLISIONS[*]

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The production of $\bar{N}_1^*$, the "anti" of the familiar $T=\frac{3}{2}$, $J=\frac{3}{2}$ pion-nucleon isobar,[1,3] has been observed in a hydrogen bubble chamber study of $\bar{p}$-p interactions.[4] The $\bar{N}_1^*$ is produced in association with the N_1^*, and within our limited statistics, the production process is consistent with single pion exchange. The evidence comes from a study of 304 four-prong events of the type

$$\bar{p}+p\to\bar{p}+p+\pi^++\pi^-. \tag{1}$$

The momentum of the incident antiproton beam[5] was 3.25 BeV/c, corresponding to a total center-of-mass energy of 2850 MeV. The 304 events were identified by a kinematic fitting procedure[6] applied to a group of four-prong events selected in the following way: A larger group of four-prong events had been analyzed for annihilation studies,[4] but not fitted to Reaction (1). All those four-prong events in the larger group which were not identified as four-pion final states (four-constraint fits), and for which the momentum imbalance of the observed tracks was less than 300 MeV/c, were selected for fitting to Reaction (1). Kinematic identification was confirmed by visual ionization estimates, which usually allowed positive identification of the proton.

Reaction (1) appears to occur primarily via pro-