[6] S. Hayakawa, Nuovo cimento 5, 608 (1957).
[7] Higashi, Oshio, Shibata, Watanabe, and Watase, Nuovo cimento 5, 597 (1957).
[8] W. Heisenberg, Z. Physik 101, 533 (1956).
[9] D. I. Blokhintsev, Usp. Fiz. Nauk 62, 381 (1957).

Translated by W. H. Furry
180

ON THE MAGNITUDE OF THE RATIO σ^-/σ^+ NEAR THE THRESHOLD OF MESON PHOTOPRODUCTION

S. P. KHARLAMOV, M. I. ADAMOVICH, and V. G. LARIONOVA

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor November 26, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) 36, 945-947 (March, 1959)

THE magnitude of the ratio of the yields of positive to negative photo mesons from deuterium $\eta = N_d^-/N_d^+$ can differ appreciably from the ratio σ^-/σ^+ for the photoproduction of π mesons from free nucleons. As we have shown earlier[1] this can be due to a difference in the final state interaction of the particles after photoproduction of a π^- or a π^+ meson on deuterium. Furthermore one has to keep in mind that the difference of the thresholds for π^- and π^+ production on deuterium can have a strong influence on the quantity η if one measures it utilizing photons close to the high energy limit of the bremsstrahlung spectrum.

In the present note the ratio σ^-/σ^+ is deduced from experimental values of η taking into account the above mentioned effects. The experimental results are given in the Table. The ratio of the π^- to π^+ yields on deuterium were measured at an angle of 73° with respect to the photon beam with bremsstrahlung of maximum energy $\nu_m = 300$ Mev[2] and at angle of 60° with bremsstrahlung of $\nu_m = 165$ Mev[3] (first row). In the second row the deduced values for the ratio σ^-/σ^+ are given. They were obtained from the experimental data by applying corrections for the Coulomb interaction of the π^- meson with the protons and of the protons with themselves, and by applying corrections to take into account that π^- and π^+ mesons of the same energy have been produced by photons of different energy.

The Coulomb corrections have been computed on the basis of Baldin's calculations[4] concerning our earlier experiments[1] on the distribution of the relative momenta, p, of the protons, and of the recoil momenta, q, in the reaction $\gamma + d \rightarrow \pi^- + p + p$ for the photon energies given in the table.

We now shall discuss in greater detail the corrections which have to be applied to account for the difference in the threshold energies for π^- and π^+ photoproduction considering the strong energy dependence of the bremsstrahlung spectrum near the upper energy tip. We will do so for the case $\nu_m = 165$ Mev.* Figure 1 shows the experimental momentum distribution of the π^- mesons from

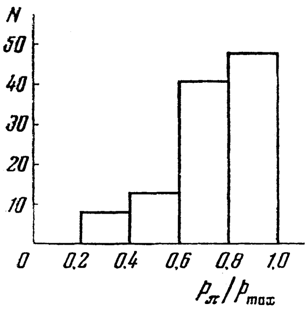

FIG. 1

the reaction $\gamma + d \rightarrow \pi^- + p + p$ for photon energies 155 — 165 Mev. It has been obtained by our method described in reference 1. On the abscissa we have plotted the ratio of the meson momentum p_π to the maximum possible meson momentum p_{max} (given by the meson emission angle θ and the photon energy). The curves in Fig. 2 show the yields $N_d^\mp(\nu)$ of π^- and π^+ mesons of energies between 6.7 and 11.7 Mev emitted at an angle of 60° with respect to the photon direction as a function of the photon energy (when $\nu_m = 165$ Mev). For the π^- mesons the momentum distribution of Fig. 1 and the cross sections for the $\gamma + d \rightarrow \pi^- + p + p$ reaction from reference 1 was utilized. For the π^+ mesons the same momentum distribution was taken and it was assumed that the cross sections are given by

ν_m	165 Mev	310 Mev			
ν	159	170	180	190	200
N_d^-/N_d^+	2.10±0.17	1.50±0.15	1.41±0.10	1.41±0.09	1.28±0.09
σ^-/σ^+	1.30±0.11	1.39±0.14	1.33±0.09	1.35±0.09	1.25±0.09

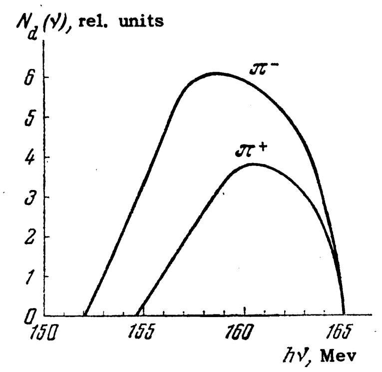

FIG. 2

$$\sigma_d^-(\nu + \Delta\nu, E_\pi)/(\sigma^-/\sigma^+),$$

where $\Delta\nu$ is the difference between the threshold energies for π^- and π^+ production on deuterium. The curves of Fig. 2 were normalized such that the ratio of the yields $N_d^\pm = \int^{\nu_m} N_d^\pm(\nu)\,d\nu$ equals the experimental value $N_d^-/N_d^+ = 2.10 \pm 0.17$.[3] Taking further into account the Coulomb correction (at a photon energy of ~ 160 Mev this amounts to 1.065) we find from the normalization the value $\sigma^-/\sigma^+ = 1.30 \pm 0.11$. Only the statistical error has been indicated. The use of the same momentum distribution for the π^+ mesons as for the π^- mesons can introduce a further error of a few percent. However, a much larger error can be present due to the uncertainty in the determination of the high energy limit of the bremsstrahlung spectrum. Thus, for example, if in the work of Carlson-Lee[3] the high energy limit were 167 instead of 165 Mev, our value of N_d^-/N_d^+ would correspond to $\sigma^-/\sigma^+ = 1.42 \pm 0.12$. The data of Carlson-Lee as reported in the abstract do not allow a more accurate determination of the quantity σ^-/σ^+ for the photon energy $\nu \approx 159$ Mev.

As can be seen from the table the ratio σ^-/σ^+ is approximately constant in the photon energy interval 159 to 200 Mev. Its value agrees well with the results of reference 1 and with the theoretical value.[5]

It should be mentioned that the influence of the sharp drop off of the bremsstrahlung spectrum near the tip has a still larger effect if one compares the π^- and π^+ yields from reactions with large difference in the thresholds. A particularly extreme example is the case of meson photoproduction on beryllium. Since π^- mesons can be created in the reaction $\gamma + Be^9 \rightarrow \pi^- + p + Be^8$ the threshold for production is roughly 17.9 Mev lower than for π^+ production. This way can be explained the anomalous behavior of the value N^-/N^+ with decreasing bremsstrahlung energy or with increasing meson energy or emission angle. This was earlier interpreted as being due to the nuclear structure or due to the special position of the weakly bound neutron. The above described effect has to be taken into account also in the study of the ratio N^-/N^+ in other complex nuclei.

*These corrections amount to around 1.5% on the values N_d^-/N_d^+ given in the table for the case with $\nu_m = 300$ Mev.

[1] Adamovich, Kuz'micheva, Larionova, and Kharlamov, J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 27 (1958); Soviet Phys. JETP **8**, 21 (1959).
[2] Benventano, Stoppini, Tau, and Beruardini, Proc. CERN Symp., Geneva, **2**, 259 (1956).
[3] D. Carlson-Lee, Bull. Am. Phys. Soc. **3**, 334 (1958).
[4] A. M. Baldin, Nuovo cimento **8**, 569 (1958).
[5] Chew, Goldberger, Low, and Nambu, Phys. Rev. **106**, 1345 (1957).

Translated by M. Danos
181

ON THE SCATTERING OF PIONS BY DEUTERONS

G. M. VAGRADOV and I. B. SOKOLOV

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor November 26, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 948-949 (March, 1959)

SEVERAL authors[1-5] have compared the results of theoretical calculations with experimental data on the elastic scattering of π mesons by deuterons.[2,6,7] Green[1] and Rockmore[3] have used the impulse approximation[8] and note the disagreement between calculated and experimental cross-sections at small angles.[2,7] Differential cross sections calculated by Bruekner's method[4] give better agreement with experiment. This is attributed to taking multiple scattering into account.[9] Bransden and Moorhouse[5] calculated π-d scattering using a variational method. They also obtained agreement with experiment, but in this method of calculation the contributions from multiple scattering are small.

We note in the following, however, that the calculation of the differential cross-section in the impulse approximation is based on different assumptions than those used either in Brueckner's method or the variational method: the impulse approxima-