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PHOTOPRODUCTION OF π^--MESONS ON NEUTRONS WITH POLARIZED PHOTONS IN THE ENERGY RANGE E_γ = 0.9 - 1.65 GEV

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1. Introduction

Both experimental and theoretical investigations of single π -meson photoproduction on nucleons in the excitation region of πN -resonances have achieved a wide-scale development in recent years. Accumulation of experimental data gave rise to carrying out of different theoretical analyses based on phenomenological photoproduction models /1,2/, and also the theory of dispersion relations and complex angular momenta /3-7/. These analyses permitted to obtain coupling constants of $(N^{*}\rightarrow N+\gamma)$ πN-resonances and compare with their values calculated in the quark model /8-9/. In the photon energy range E_{γ} =0.8-2 GeV, where tens of resonances may be excited, systematic data on different polarization experiments /10/ are necessary to determine individual resonance contributions in the amplitudes of photoproduction processes. Here the availability of data on photoproduction of π -mesons on protons and neutrons is rather important, which will allow one to determine the isotopic structure of photoproduction amplitudes /11-12/.

At present the experimental data on neutron targets are worse than the proton data both in quality and quantity. In particular, in the photon energy range above 0.8 GeV the data on polarization investigations are practically absent.

In this work the experimental technique is described and the results of the photoproduction of π^--mesons cross-section asymmetry measurements on neutrons D_2 by polarized photons are given for the energy range E_γ =0.9÷1.65 GeV and at π^--meson emission angles $\theta^*_{\pi^-}$ = 30° - 60° in the c.m.s.

The measurements of π^+-photoproduction cross-section asymmetry on protons of deuterium target and on hydrogen with the aim to determine the influence of deuteron effects on the cross-section asymmetry were carried out.

2. Experimental layout

The experiment was carried out with the linear-polarized photon beam of the Yerevan electron synchrotron. Linear-polarized photons were generated in a monocrystal diamond target at electron energy 4.6 GeV /13/. Both vertical and horizontal photon polarizations were obtained by the choice of the crystal orientations [022] and [02$\bar{2}$] , respectively /14/. The beam polarized photons went through a system of collimators and sweeping magnets and fell onto the liquid-deuterium (hydrogen) target /15/. The beam sizes near the target were 10 x 10 mm^2. The target vessel with Mylar windows had a cylindrical shape of 100 mm length and 50 mm diameter and was adjusted along the axis of the photon beam. Monitoring of photons was performed by a Wilson-type quantameter. The spect-

rum of γ-quanta was measured and controlled by a pair spectrometer in the course of statistics. A typical spectrum of polarized photons at a peak energy value E_γ = 1.5 GeV as well as the polarization calculation curve are given in Fig.2.

The $\pi^\mp$-meson detection was carried out using a magnetic spectrometer /16/. The magnetic spectrometer involving two focussing lenses of ML-16 type, the analyzing magnet SP-12 and a counter telescope S_1 - S_5 , had a momentum acceptance $\Delta P/p \simeq 5\%$ and a solid angle capture $\Omega \simeq 1.2 \times 10^{-3}$ ster. To separate π^+-mesons from protons in the spectrometer was used time-of-flight technique on the base of flight $\simeq$ 10.5 m between the counters S_1 and S_4 using the compensation scheme /17/. With the aim to reduce the effects of inelastic interaction and multiple scattering of π-mesons in the spectrometer polyethilen balloons with helium along the particles trajectory were placed. To detect recoil protons and neutrons in the experiment the module time-of-flight spectrometer that involved 12 blocks of scintillation counters assembled as matrices 4 x 3 in a metal frame, was used. Each counter consisted of a plastic scintillation radiator with dimensions 23 x 23 cm^2 in section and 30 cm in length along the beam that was scanned by the photomultiplier ФЭУ-30. The time-of-flight analysis of nucleons was performed on the base of flight $L \simeq$ 3.3 m from the target to the spectrometer counters. The pulses from two photomultipliers of the magnetic spectrometer counter S_1 were used for start signals. A compensation method was also used in the electronic logic of the time-of-flight analysis of recoil nucleons. The detection threshold of the time-of-flight spectrometer counters at measurements on the D_2 -target was equal to $\simeq$ 20 MeV (equivalent proton energy), and the time resolution (σ_t) was about 2 nsec in the case of the proton recording.

The experiment was carried out "on line" with a set of computers PDP-8, PDP-9 and M-222 /18/.

3. Measurement technique and data processing

The kinematical parameters of the reactions under investigation were determined from the Monte-Carlo simulation of the reactions.

The nuclear motion of nucleons in the deuterium target was described using the Hulthen wave function /19/. The corresponding momentum distribution of nucleons in the target is shown in Fig.3 (solid curve). The effects of both ionization losses and multiple scattering as well as π -meson decay during flight with a possible recording of μ -mesons were taken into account during the simulation of π -mesons detection in the magnetic spectrometer. The geometric efficiency of detection of the recoil nucleons corresponding to the time-of-flight spectrometer aperture was 40%-70%. The resolving power of the facility over the photon energy and emission angle of π^- -mesons in the c.m.s. is given in Table 1.

The efficiency of detecting the reactions under conside-

ration depended on the momentum of the target nucleons, which fac resulted in reducing of a contribution of events with large values of momenta. For instance, the relative contribution of events with the value of the target neutron momentum $E_p \gtrsim$ 100 MeV/c was less than 4%. The effective momentum distribution obtained from the simulation results for kinematics E_γ = 1.05 GeV, $\theta^*_{\pi^-}$ = 50° is shown in Fig.3 (hystogram).

The results of the time-of-flight analysis of recoil nucleons were used at data processing. Extraction of the process under investigation was performed by a characteristic peak in the time-of-flight spectrum (Fig.4). The background events due to both multiparticle processes and random coincidences were approximated by some function defined by the χ^2 minimization method. The relative value of the background usually made 3-4% of the peak value and did not exceed 10%. Dotted curves in Fig.4 correspond to the simulation results with account of the resolving power of the time-of-flight spectrometer. As an additional test to the extraction procedure of the process under investigation, the angular distribution of recoil protons at kinematics E_γ = 1.05 GeV and θ^*_π = 50° is measured. Both measurement results for the projection of emission angle of protons from the target in the horizontal plane ($\theta_p^\perp$) in lab. system and the simulation results were in agreement (Fig.5). A time-of-flight spectrum corresponding to $70° \leq \theta_p^\perp \leq 78°$ angular interval, where the relative yield of the reaction was insignificant, is shown in Fig.4. Its comparison with the background approximation results, also verifies the correctness of the extraction procedure of the process under investigation.

The contribution of the background processes from the target casing was determined in measurements with an empty target and made a value less than 1%.

The cross-section asymmetry Σ was defined using the yields of single π^--meson photoproduction $C_\perp$ and $C_\parallel$, corresponding to perpendicular and parallel polarizations of photons relative to the plane of the reaction:

$$\Sigma = \frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = \frac{C_\perp - C_\parallel}{C_\perp + C_\parallel} \cdot \frac{1}{P_\gamma}$$

where P_γ is the effective photon polarization. The obtained results on the cross-section asymmetry Σ in the reaction $\gamma + d \to \pi^- + p + p_s$ are given in Table 1. The errors in the value of Σ involve a statistical error in determining the values $C_\perp$ and $C_\parallel$, as well as an error ($\simeq$ 10%) in the value of effective photon polarization.

Differential cross sections of the reaction are calculated using the values $C_\perp$, $C_\parallel$ and simulation results (Table 1):

$$\frac{d\sigma}{d\Omega} = \frac{1}{2}\left(\frac{d\sigma_\perp}{d\Omega} + \frac{d\sigma_\parallel}{d\Omega}\right)$$

Our data on differential cross sections agree with the earlier published results /20-21/ within the range of possible systematic errors [1] $\simeq$ 10%.

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[1] Statistic errors were 3-5%.

The ratio of π^+-photoproduction asymmetries on the deuterium target's protons and on hydrogen is measured at E_γ = 1.35 GeV and $\Theta^*_{\pi^+}$ =40°. The obtained value of the quantity

$$\frac{\Sigma(\gamma + d \to \pi^+ + n + n_s)}{\Sigma(\gamma + p \to \pi^+ + n)} = 0.94 \pm 0.2$$

along with results of analogous measurements at other energies /22-23/ shows that the deuteron effect contribution does not exhibit itself within experimental errors.

4. Results and discussions

In Figs.6 and 7 experimental data on the cross-section asymmetry of the reaction $\gamma + n \to \pi^- + p$ are compared with predictions of theoretical analyses /2,4,7/. At the photon energy $E_\gamma \simeq$ 1.05 GeV (the III-resonance region) these analyses consider a contribution of about ten resonances to the amplitude of single π-meson photoproduction processes. The values of coupling constants of neutral resonances, obtained from the analyses, in most cases disagree with each other, which is mainly due to the poor experimental data on a neutron target.

Our results on the angular dependence of the asymmetry Σ at E_γ = 1.05 GeV (Fig.6) are in a better agreement with results of Ref./2/, although one can observe a qualitative agreement with data of Ref./7/ and two solutions of the analysis /4/.

The energy dependence of the asymmetry Σ at $\Theta^*_{\pi^-} = 40^\circ$, 50° is given in Fig.7. While comparing experimental data with results of the analysis /7/ , where a contribution of highest resonances (D_{35} (2000), H_{19} (2220)) is taken into account, it is difficult to draw definite conclusions on their agreement, although in the energy dependence of Σ for $\Theta^*_{\pi^-} = 50^\circ$ one can observe changing of the asymmetry sign at $E_\gamma \simeq 1.5$GeV, which corresponds to the prediction of the analysis.

When using isotopic properties of the photon ($I = 0,1$), the amplitudes of single π -meson photoproduction on nucleon can be presented in the form /1/

$$A_{\pi^+} = A^S + A^V$$

$$A_{\pi^-} = A^S - A^V$$

As one can see from the formulae, a contribution of a purely isoscalar A^S (isovector A^V) amplitude will bring to the equality of observable values (σ , Σ , P , T ...) for the both processes. The energy dependence of the difference between the asymmetry Σ^- in reactions $\gamma + n \to \pi^- p$ (present data) and our earlier results on Σ^+ in the reactions $\gamma + p \to \pi^+ + n$ /24/ for $\Theta^*_\pi = 40^\circ$ is shown in Fig.8, where the analogous dependence $\Delta\Sigma$ at $\Theta^*_\pi = 90^\circ$ on the base of data of Ref./25/ is also given. As is seen from Fig.8, in the photon energy region $E_\gamma = 0.9$-1.35 GeV $\Delta\Sigma$ is nonzero, which verifies the presence of both isovector and isoscalar amplitudes in the given energy range. Nearby $E_\gamma \simeq 1.5$ GeV

the values of Σ^+ and Σ^- coincide within the errors. A zero value of $\Delta\Sigma$ at this energy can be explained by the dominance of resonance F_{37} (1950) ($I = 3/2$).

The dominance of resonance F_{37} (1950) is predicted in the quark model /26/, and also is verified in Ref./27/ by experimental data on angular dependence of differential cross section of the reaction $\gamma + p \to \pi^0 + p$. However, in the case of F_{37} (1950) dominance the quark model predicts the value $\simeq$ 0.9 for asymmetries Σ^+ and Σ^- in the interval $\Theta^*_\pi = 40^\circ$- 140°, what disagrees with experimental data. On the basis of stated facts one can conclude that in the process of π -meson photoproduction on nucleon at $E_\gamma \simeq 1.5$ GeV along with the F_{37} (1950) resonance other resonances (e.g. F_{35} (1890), P_{31} (1950), D_{35} (2000)) with isospin $I = 3/2$ also participate.

It should be noted in conclusion, that carrying out of repeated analyses using our data on π -meson photoproduction on neutrons will allow to specify contributions of each of resonances in the given energy range.

Table 1

E_γ (GeV)	$\Theta_\pi^{c.m.c}$ (deg)	Σ	$\frac{d\sigma}{d\Omega}^{c.m.c}$ ($\mu b/sr$)
C.9 ± 0.028	40 ± I	0.38 ± 0.065	4.I ± 0.46
I.05 ± 0.030	30 ± 0.8	0.43 ± 0.065	4.I ± 0.45
I.05 ± 0.032	10 ± I	0.28 ± 0.045	3.9 ± 0.42
I.05 ± 0.037	50 ± I,5	0.I ± 0.04	3.5 ± 0.38
I.05 ± 0.042	60 ± 2	-0,I7 ± 0.045	2.I ± 0,23
I.2 ± 0.035	40 ± I	0.2I ± 0.045	3.3 ± 0.35
I.2 ± 0.040	50 ± I.4	0.0I ± 0.04	3.0 ± 0.33
I.35 ± 0.039	40 ± I	0.04 ± 0.05	2.5 ± 0.27
I.35 ± 0.043	50 ± I.3	0.04 ± 0.04	2.0 ± 0.2I
I.5 ± 0.042	40 ± I	0.I4 ± 0.055	I.7 ± 0.I8
I.5 ± 0.047	50 ± I.3	-0.I7 ± 0.06	I.I ± 0.I2
I.65 ± 0.047	40 ± 0.9	-0.0I ± 0.065	I.2 ± 0.I3

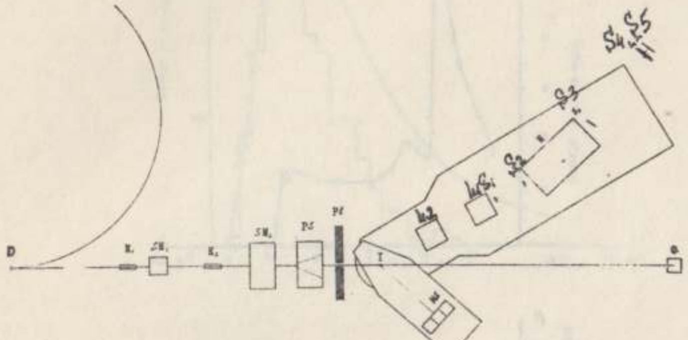


Fig.1 Experimental layout: D - a diamond target, K - collimators, SM - sweeping magnets, PS - pair spectrometer, T - liquid-deuterium (hydrogen) target, M - magnetic spectrometer, NS - time-of-flight spectrometer, Q - quantameter.

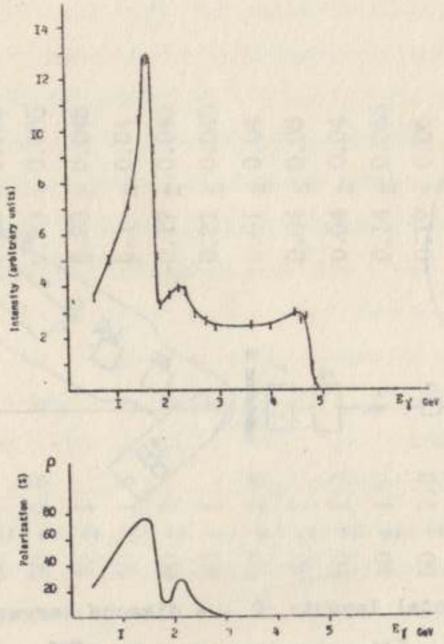
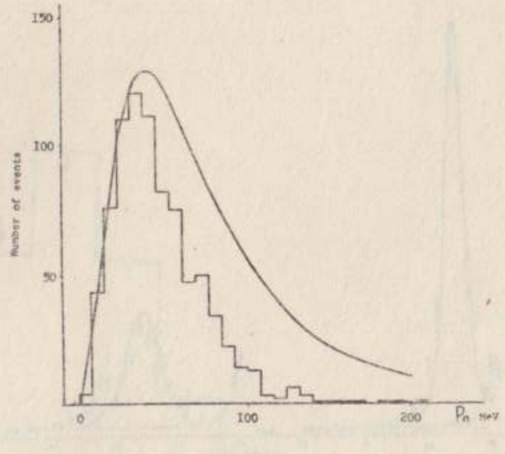


Fig.2 Photon spectrum and calculated polarization curve at $\sum_{\gamma}^{peak} = 1.5$ GeV.



ig.3 Momentum distribution of nucleons in the target (see the text).

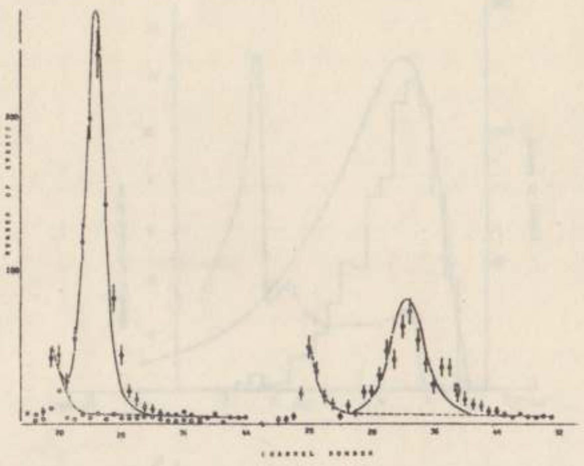


Fig.4 Time-of-flight spectrum of recoil protons in the reaction $\gamma + d \rightarrow \pi^- + p + p_s$ at kinematics E_γ = 1.05 GeV and $\Theta^*_{\pi^-}$ = 50° (left) and $\Theta^*_{\pi^-}$ = 30° (right);
● - experimental points, —— data on M-K calculations, — — — approximated background, o time-of-flight spectrum at "disturbed" kinematics $\Theta^{\perp}_{p}$ = 70°-78° (see the text). The channel weight is ≃ 2 nsec.

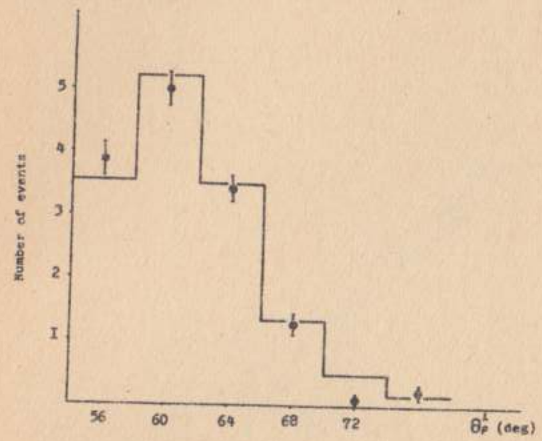


Fig.5 Angular distribution of recoil protons in the reaction $\gamma + d \rightarrow \pi^- + p + p_s$ at E_γ = 1.05 GeV and $\Theta^*_{\pi^-}$ = 50° (relative units); solid curve - data on MK calculations.

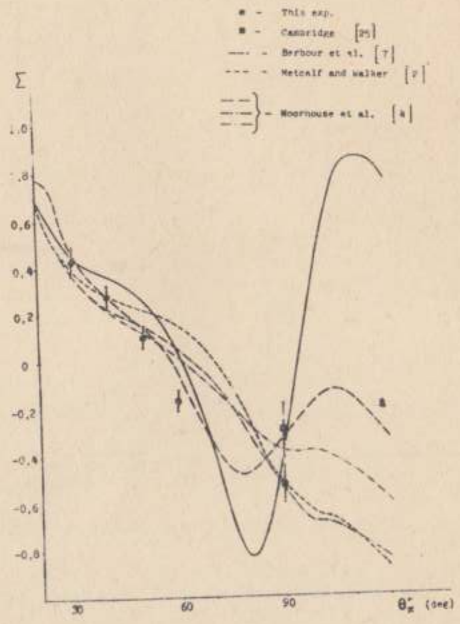


Fig.6 Angular dependence of asymmetry Σ in the reaction $\gamma + n \longrightarrow \pi^- + p$ at $E_\gamma = 1.05$ GeV.

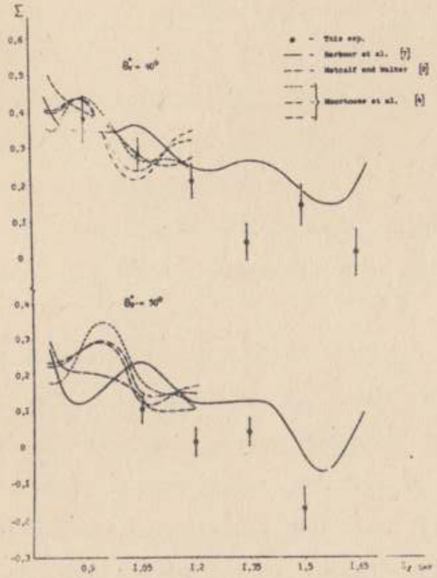


Fig.7 Energy dependence of Σ at $\Theta^*_{\pi^-} = 40^o$ and 50^o.

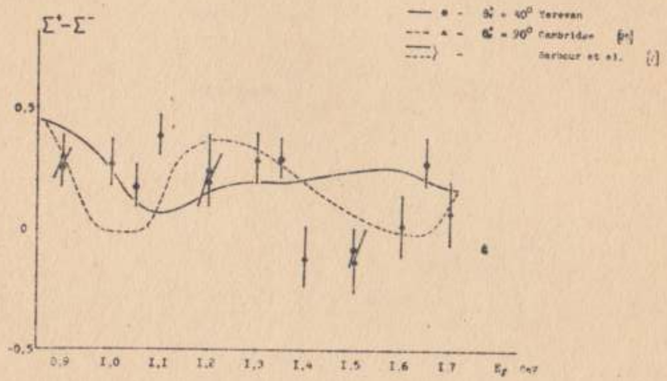


Fig.8 Energy dependence of difference $\Delta\Sigma$

$$\Delta\Sigma = \Sigma^{+}(\gamma + p \to \pi^{+} + n) - \Sigma^{-}(\gamma + n \to \pi^{-} + p) \text{ at}$$
$\theta^{*}_{\pi} = 40^{\circ}$ and 90°.

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ФОТОРОЖДЕНИЕ π^- - МЕЗОНОВ НА НЕЙТРОНАХ
ПОЛЯРИЗОВАННЫМИ ФОТОНАМИ В ИНТЕРВАЛЕ ЭНЕРГИЙ
E_γ = 0.9 - I.65 ГЭВ
(на английском языке)

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