Polarization of protons from the $\gamma + p \to \pi^0 + p$ reaction produced by 692-1028 MeV photons at 90° in the center-of-mass system

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Measurements are reported of the polarization of recoil protons from the $\gamma + p \to \pi^0 + p$ reaction for 692—1028 MeV photons at 90° in the center-of-mass system, using an energy resolution ΔE_γ = 13—22 MeV. It is found that this polarization is strongly dependent on the energy resolution and exhibits a minimum at photon energies between 900 and 1000 MeV. Up to photon energies of 900 MeV there is good agreement between experiment and calculations based on the isobaric model, but there is a discrepancy at higher energies.

Detailed studies of the photoproduction of pions on nucleons are of great importance for the understanding of many theoretical problems connected with the interaction of these particles. More accurate measurements of pion-nucleon scattering have become available in recent years, and this has permitted a more detailed phase analysis to be carried out for the pion-nucleon scattering process.[1-4] This analysis has led to the discovery of new resonant states of the pion-nucleon system in the final state. Studies of the contribution of these resonance states to photoproduction processes require an unambiguous analysis of these processes. Before an analysis of this kind can be carried out, experimental data must be available on the differential cross sections for the photoproduction of single pions on nucleons, the polarization of the recoil protons, the asymmetry in the pion production by polarized photons, and the asymmetry introduced by a polarized target.

Existing experimental data were sufficient for the analysis in the region of the first and second resonances.[5,6] In this energy range the main contribution to the amplitude for the photoproduction of single pions on nucleons is due to the resonant P_{33}, D_{13}, and S_{11} amplitudes. The presence of a large number of resonances at higher photon energies leads to a considerable complication in the analysis of the photoproduction of single pions on nucleons, and requires a greater volume of experimental data, especially data on the polarization of protons, the asymmetry in the production of mesons by polarized photons, and the asymmetry introduced by polarized targets.

Until now there has been the single paper by Walker,[5] in which the isobaric model was used to carry out an analysis up to E_γ = 1200 MeV. Walker has carried out a theoretical fit to existing experimental data on the energy dependence of the polarization of photons from the $\gamma + p \to \pi^0 + p$ reaction. Good agreement was found with the experimental data reported by Lundquist et al.[6] up to 900 MeV.

Lundquist et al.[6] have reported a structure in the energy dependence of the polarization of protons emitted at 90° c.m.s. at photon energies of 700—1000 MeV. However, more systematic polarization measurements in this energy range are necessary for the elucidation of the details of the structure. We have therefore carried out measurements of the polarization of recoil protons from the $\gamma + p \to \pi^0 + p$ reaction in the photon energy range 692—1028 MeV at 90° c.m.s. at intervals of about 25 MeV, using an energy resolution of about 18 MeV.

EXPERIMENTAL METHOD

The experiment was carried out using the photon beam of the Kharkov 2 GeV linear accelerator. The experimental setup is illustrated in Fig. 1. The bremsstrahlung beam, 15 mm in diameter, was intercepted by a hydrogen target and then monitored by a Wilson photon counter. The target was a cylindrical container, 50 mm in diameter and 30 mm high, filled with liquid hydrogen. The body of the target was made of 65 μ duraluminum. The momentum analysis of secondary protons was carried out with a magnetic spectrometer having an angular aperture of about ±0.5°, and the protons were recorded with a spark-chamber telescope.[7]

Two versions of the telescope were used, depending on the energy of the recorded protons. For protons with energies between 120 and 220 MeV we used a 10-gap spark chamber with foil electrodes (IK-10) and a 42-gap chamber with graphite electrodes (IK-42).[7] The former was designed to define the initial direction of the proton track entering the IK-42 chamber whose electrodes were used as the polarization analyzers.

Protons with energies in excess of 220 MeV were recorded with a 15-gap spark chamber (IK-15) with graphite electrodes of 250 × 250 × 6.7 mm. The first five gaps in this chamber were used to define the initial direction of the track, and the last ten gaps of the IK-15 and the electrodes of the IK-42 chamber were used as analyzers. When the energy of the recorded protons was in excess of 300 MeV, a copper attenuator of appropriate thickness was introduced into the telescope. Protons stopping in the analyzing chamber of the IK-42 system were identi-

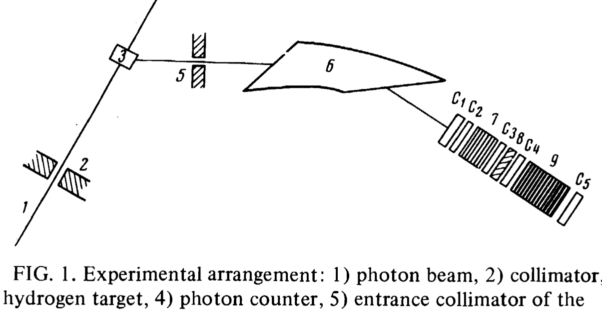

FIG. 1. Experimental arrangement: 1) photon beam, 2) collimator, 3) hydrogen target, 4) photon counter, 5) entrance collimator of the magnetic spectrometer, 6) magnetic spectrometer, 7) IK-10 (IK-15), 8) attenuator, 9) IK-42, C_1–C_5 scintillation counters.

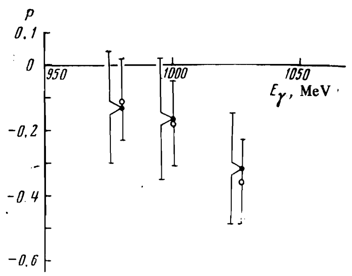

FIG. 2. Polarization of protons from the $\gamma + p \to \pi^0 + p$ reaction: ●—$\Delta E_{scat} \leq 3$ MeV, ○—$\Delta E_{scat} \leq 10$ MeV.

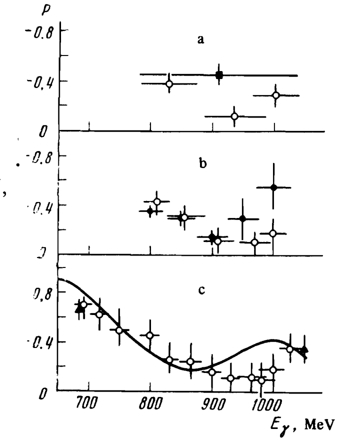

FIG. 3. Polarization of protons emitted at 90° CM in the $\gamma + p \to \pi_0 + p$ reaction as a function of energy: a) $\Delta E_\gamma = \pm 50$ MeV, b) $\Delta E_\gamma = \pm 30$ MeV, c) $\Delta E_\gamma = \pm 18$ MeV. ○—present results, ■—taken from [10], ●—taken from [6], ▲—taken from [11].

fied by C_1—C_4 coincidences and an anticoincidence with C_5, and the corresponding output pulse was used to switch the high-voltage generator.

Two mutually perpendicular projections of the track were photographed on 35 mm film, using a special optical system.

ANALYSIS OF RESULTS

The simultaneous use of the spark-chamber telescope and the magnetic spectrometer enabled us to record simultaneously the proton spectrum both in a broad momentum range ($\Delta p/p = 9\%$) and in individual parts of the spectrum ($\Delta p/p = 0.5\%$), and to determine the proton polarization simultaneously in a number of energy bands with given resolution in E_γ.[8]

The spark-chamber telescope was mounted after the spectrometer in such a way that the second electrode in IK-42 system lay along the focal line of the spectrometer. This enabled us to calibrate the proton range as a function of the coordinate of the point of intersection with the focal line. This could be done to an accuracy of better than ±3 MeV, so that the elastic scattering of protons by carbon could be separated from the inelastic scattering with the excitation of low-lying levels of this nucleus.

The experimental data were analyzed by allowing for "pure" elastic scattering ($\Delta E_{scat} \leq 3$ MeV) and scattering with $\Delta E_{scat} \leq 10$ MeV. This is illustrated in Fig. 2, from which it is clear that the two polarizations do not differ in absolute magnitude by more than 0.04, but for $\Delta E_{scat} \leq 10$ MeV the statistical uncertainties are much less than for $\Delta E_{scat} \leq 3$ MeV. To calculate the polarization, we therefore selected cases of proton scattering by the carbon plates of the analyzing chamber, which satisfied the condition

$$E_{pr} - (E_t + \Delta E_p) \leq 10 \text{ MeV},$$

where E_{pr} is the kinetic energy of a proton entering the analyzing chamber, E_t is the total energy lost by the proton before and after the scatter, as determined from the range-energy relation, and ΔE_p is the energy lost by the proton at the point of scattering as a result of elastic scattering through a given angle.

120 000 photographs were obtained in the course of the experiment. The selection of proton tracks scattered in the carbon, and corrections for track distortion by the optical system of the telescope, were carried out as described in[9]. The proton polarization was calculated by the maximum-likelihood method.

RESULTS

The energy dependence of the polarization depends on the energy resolution ΔE_γ. We have carried out an experimental study of the polarization of recoil protons in the $\gamma + p \to \pi^0 + p$ reaction at 90° c.m.s. as a function of ΔE_γ. The results are shown in Fig. 3.

Figure 3a shows the energy dependence of the proton polarization for $\Delta E_\gamma = 50$ MeV together with the proton polarization measured by Mencuccini[10] with $\Delta E_\gamma = \pm 130$ MeV. It is clear from the figure that by reducing ΔE_γ to 50 MeV we achieved a substantial reduction in the polarization. Further reduction of ΔE_γ down to 30 MeV (Fig. 3b) leads to a more rapid variation in the polarization with the energy E_γ. Figure 3b also shows the proton polarizations for the $\gamma + p \to \pi^0 + p$ reaction measured by Lundquist et al.[6] with an energy resolution of about 25 MeV. Up to photon energies of 900 MeV there is satisfactory agreement between our results and those reported in[6]. However, there is a substantial discrepancy at 1000 MeV, and this may be connected with an incorrect extrapolation of the angular dependence of the polarization at this energy to the 90° c.m.s. angle, which was carried out in[6].

Figure 3c and the table show the polarization of protons from the $\gamma + p \to \pi^0 + p$ reaction at 90° c.m.s. in the photon energy range 692—1028 MeV measured with an energy resolution $\Delta E_\gamma = \pm(13-22)$ MeV. As the photon energy increases from 700 to 900 MeV, the polarization decreases in absolute magnitude, and shows a minimum at energies between 900 and 1000 MeV. Figure 3c also shows measurements of proton polarization for the same reaction at 90° c.m.s. performed by Blüm et al.[11] The solid line was calculated by Walker[5] using the isobaric model.

Figure 4 shows the energy dependence of the first coefficient in the expansion for the angular dependence of the polarization which is determined by the imaginary part of the interference amplitudes with opposite parities:

$$A = \frac{k}{q} P(E, 90^\circ \text{c.m.s.}) \frac{d\sigma}{d\Omega}(E, 90^\circ \text{ c.m.s.}),$$

where $d\sigma/d\Omega$ is the cross section for the production of single neutral pions in hydrogen,[12] k is the photon momentum, q is the neutral-pion momentum, and P is the polarization of protons which we have measured. The same figure shows the calculated dependence of this coefficient, expressed in terms of the complete helicity amplitudes H_1, H_2, H_3, and H_4 for the photoproduction of single neutral pions on protons

$$A = -\text{Im}\,(H_1 H_3^* + H_2 H_4^*).$$

The values of the helicity elements $A_{l\pm}$ and $B_{l\pm}$ which determine these amplitudes were taken from[5].

E_γ, MeV	$\pm\Delta E_\gamma$, MeV	Number of cases	P	$\pm\Delta P$	A, μb/sγ γb/s	$\pm\Delta A$, μb/sγ	E_γ, MeV	$\pm\Delta E_\gamma$, Мэв	Number of cases	P	$\pm\Delta P$	A, μb/sr	$\pm\Delta A$, μb
692	13	416	–0.70	0.13	–2.90	0.55	900	15	302	–0.16	0.14	–0.42	0.37
718	13	345	–0.62	0.14	–2.90	0.65	930	15	468	–0.11	0.11	–0.26	0.26
750	15	266	–0.52	0.15	–2.50	0.72	965	22	366	–0.12	0.14	–0.25	0,28
800	15	522	–0.45	0.11	–1.65	0.40	980	21	355	–0.11	0.13	–0.19	0.21
831	15	461	–0.26	0.11	–0.80	0.32	1000	21	374	–0.18	0.13	–0.33	0.23
866	16	208	–0.25	0.15	–0,62	0.35	1028	18	320	–0.36	0.13	–0.61	0.21

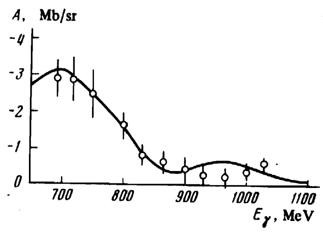

FIG. 4.

It is clear from Figs. 3c and 4 that the curves calculated from the isobaric model, taking into account the resonant amplitudes with total angular momentum $J \leq 5/2$, are in adequate agreement with the experimental data up to E_γ = 900 MeV, but at higher energies there is a discrepancy which can probably be removed either by altering some of the parameters, or by including amplitudes with $J > 5/2$, or by taking into account diagrams with ω–exchange in the t-channel.

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