Polarization of secondary protons from the reaction $\gamma + p \rightarrow \pi^0 + p$ in the region of the third resonance

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Measurements of proton polarization from the reaction $\gamma+p \rightarrow\pi^0+p$ are reported in the photon-energy range 980–1225 MeV at a center-of-mass angle 90°. A peak is observed in the energy dependence of the polarization with a maximum at $E_\gamma\sim 1090$ MeV. A comparison is given of the polarization values obtained with those calculated by Walker. A disagreement is observed between the experimental and theoretical polarization values.

Investigation of the various characteristics of pion photoproduction from nucleons play a large role in the understanding of many theoretical and practical problems of the πN interaction. At the present time extensive experimental data have been accumulated in the resonance region of photon energies on the total and differential cross sections for pion photoproduction by unpolarized photons in unpolarized targets. However, the existence of only these observations does not permit a unique multipole analysis of the photoproduction of π mesons from nucleons.

Another important characteristic—the polarization of the secondary protons—has been studied in greatest detail in the reaction

$$\gamma+p\rightarrow\pi^0+p \qquad (1)$$

in the photon-energy interval[1] 500—900 MeV. This has made it possible to carry out a more detailed multipole analysis in the region of the second resonance.[2-4] In the region of the third resonance the experimental data on proton polarization has a random nature,[5-7] although this region of the πN interaction presents substantial interest. This is due to the existence in this region of a large number of resonance πN states (S_{31}, D_{15}, D_{33}, F_{15}, S_{11}, P_{11}, P_{13}, F_{35}, P_{31}, F_{37}), the greater part of which follow from the phase-shift analysis of πN scattering, and therefore their role in the photoproduction process has not been clarified at the present time.

Since the polarization is more sensitive than the differential cross sections to the contributions of small partial amplitudes, new information on this important characteristic may provide substantial assistance in solution of the problem of the contributions of the amplitudes of these resonances to the photoproduction of π mesons from nucleons. In the present work, which is a continuation of a series of investigations of proton polarization in photoproduction of single π^0 mesons from nucleons,[8] we have measured the polarization of protons from reaction (1) at 90° in the center of mass in photon-energy interval 980—1225 MeV. The technique used permitted measurements with a resolution in E_γ of $\sim\pm(12—20)$ MeV and with an energy step $\sim$20 MeV.

EXPERIMENTAL METHOD

The experiment was performed in the bremsstrahlung beam of the Khar'kov 2-GeV electron linear accelerator. The experimental arrangement has been described previously.[8]

Secondary protons from reaction (1) were analyzed in momentum by a magnetic spectrometer with an acceptance angle $\pm0.5°$ and were recorded by a spark-chamber telescope (SCT). The polarization of the protons was determined by the asymmetry of their scattering in the SCT. Figure 1 shows the arrangement of the telescope. The telescope contained a spark chamber with 42 graphite electrodes (SC-42).[9] The electrode dimensions were $350 \times 350 \times 7$ mm, and the total amount of material in the graphite was 46 g/cm^2, which corresponds to the maximum range of a proton with energy 250 MeV. For measurement of the polarization of protons with energies above 250 MeV, graphite blocks (B1, B2, B3) were placed in front of the SC-42 chamber, the thickness of the blocks being chosen in accordance with the energy of the detected protons. To determine the direction of the incident particle and particles scattered in the blocks, a four-gap spark chamber SC-4 containing five aluminum electrodes of diameter 190 mm and thickness 0.15 mm was placed in front of each block.[10] The presence of these chambers provides the possibility of using the blocks simultaneously to slow down and analyze the asymmetry in scattering of the protons by carbon nuclei and in this way to increase the scattering efficiency substantially.

Events with stopping of a proton in the SC-42 chamber were recorded by coincidence of the pulses of scintillation counters C_1 and C_2 and anticoincidence of counter C_3. Two mutually perpendicular projections of the track were photographed in one frame of 35-mm film by means of the optical system described in ref. 11. A technique of calibration of the proton ranges by means of the coordinate of their traversal of the spectrometer focal line[12] permitted use for calculation of the polarization of all cases of proton scattering in carbon satisfying the selection criteria of ref. 11. For a momentum acceptance of 8% the proton-scattering efficiency in an angular interval 5—25° was 6—7%. In the course of measuring the polarization of protons from reaction (1) we obtained 130 000 stereophotographs, of which 8440 satisfied the selection criteria for calculation of the polarization.

The tracks were measured with the aid of semiautomatic measuring devices connected to Dnepr-22 and M-220 computers. The maximum errors in measurement of the azimuthal and polar scattering angles φ

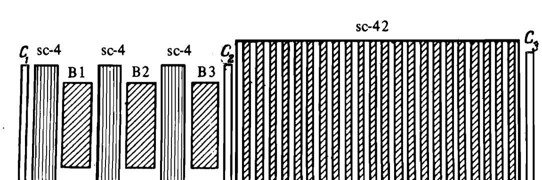

FIG. 1. Arrangement of telescope.

and θ were respectively 0.065 and 0.0137 rad. The maximum error in determination of the scattered-proton energy, which was due mainly to the error in determining the point of scattering in the graphite blocks, was ±4.5 MeV.

Use of the SCT at the exit of the magnetic spectrometer permits measurement of the proton polarization simultaneously in the four two-percent momentum intervals accepted by the telescope and which determined the energy resolution of the experiment, and obtaining information on polarization for any photon energy in the energy interval measured. The proton polarization was calculated by computer by the method of maximum likelihood.

EXPERIMENTAL RESULTS

In order to check the experimental method we made measurements of the proton polarization for the same photon energies E_γ = 980, 1000, and 1028 MeV used in our previous work.[8] Table I lists the results of the present work and of ref. 8. Comparison of the polarization can be used to obtain new experimental information.

The proton-polarization values and their statistical errors obtained in the present work are given in Table II. Also shown are the polarization cross sections A(E) calculated from the expression

$$A(E)=\frac{k}{q}\frac{d\sigma}{d\Omega}(E, 90^\circ \text{ c.m.s.})P(E, 90^\circ \text{c.m.s.}), \quad (2)$$

where k and q are the momenta of the photon and π^0 meson in the center of mass, $(d\sigma/d\Omega)(E, 90^\circ$ c.m.s.) and P(E, 90° c.m.s.) are the cross section for photoproduction of single π^0 mesons from protons[12] and the polarization of recoil protons at 90° c.m.s. obtained in the present work.

In Fig. 2 we have shown the experimental energy dependence of the polarization of protons from reaction (1) in the γ-ray energy interval 550–1250 MeV at a center-of-mass angle of 90°. The energy dependence of the polarization has a sharply expressed resonance nature. There are two peaks with maximum polarization values of the order −0.7 in the region of the second resonance ($E_\gamma \approx$ 700 MeV) and the third resonance ($E_\gamma \approx$ 1090 MeV). The presence of the first peak was

TABLE 1.

$P \pm \Delta P$	E_γ, MeV		
	980	1000	1028
Present work	−0.175±0.115	−0.195±0.065	−0.362±0.064
[8]	−0.11±0.13	−0.18±0.13	−0.36±0.13

TABLE 2.

E_γ, MeV	$\pm \Delta E_\gamma$, MeV	θ_{cms}, deg	Number of events	$P \pm \Delta P$	$A \pm \Delta A$. μb/sr
980	12	90.9	466	−0.175±0.115	−0.302±0.181
1000	13	90.7	971	−0.195±0.065	−0.313±0.128
1028	13	90.5	1111	−0.362±0.064	−0.570±0.128
1050	14	90.3	1363	−0.392±0.059	−0.561±0.118
1057	14	90.3	1105	−0.442±0.065	−0.404±0.131
1073	15	90.1	1264	−0.547±0.062	−0.650±0.148
1090	15	90.0	1242	−0.701±0.061	−0.747±0.125
1100	15	89.9	1437	−0.636±0.057	−0.678±0.117
1119	16	89.7	996	−0.573±0.070	−0.541±0.111
1136	16	89.6	833	−0.468±0.075	−0.427±0.135
1152	17	89.5	760	−0.280±0.077	−0.244±0.089
1175	18	89.3	592	−0.324±0.085	−0.296±0.135
1198	19	89.1	525	−0.430±0.089	−0.349±0.130
1225	20	88.8	349	−0.325±0.120	−0.198±0.100

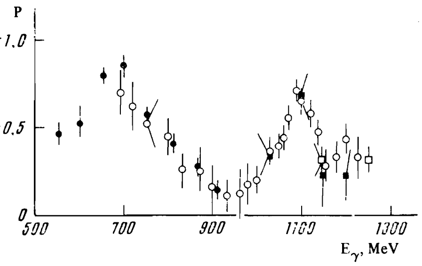

FIG. 2. Experimental energy dependence of polarization of protons from reaction (1) at 90° c.m.s. in the photon-energy interval 550–1250 MeV: hollow circles) results of the present work and ref. 8; solid circles) ref. 1; hollow squares) ref. 5; solid squares) ref. 6.

demonstrated by Lundquist.[1] The peak in the vicinity of the third resonance is observed for the first time in the present work.

The existence of the peak at E_γ = 700 MeV can be explained by interference of S_{11} and D_{13} amplitudes with P_{11} and P_{33} amplitudes, which is consistent with the results of Walker's phenomenological analysis.[13] The existence of the peak at E_γ = 1090 MeV is not confirmed by the results of this analysis, which was carried out on the basis of data only on the differential cross sections in the region of the third resonance. Figure 3 shows the energy dependence of the polarization cross section (2) in the photon-energy interval 950–1250 MeV. This dependence, calculated with the amplitudes for photoproduction of single π^0 mesons from protons taken from the work of Walker,[13] is represented by a curve whose maximum is displaced toward lower photon energies relative to the experimentally observed maximum by an amount of the order 130 MeV.

As is well known at the present time, pion photoproduction processes in the region of the third resonance are dominated by the F_{15}-resonance amplitude. Near this resonance there exist the resonances S_{31}(1630), D_{15}(1670), D_{33}(1670), S_{11}(1700), and D_{13}(1700). Since the parities of the F_{15}(1690) resonance and the remaining nearby resonances have opposite sign, the interference of their amplitudes can lead to this type of energy dependence in the third resonance region. It is necessary to carry out a new multipole analysis of the experimental data obtained recently[12,14] with inclusion of the results of the present work in order to determine the contributions of the resonance amplitudes to the amplitude for photoproduction of single π^0 mesons from protons in this energy region.

In Table III we have given the values of the coefficients A, B, C, and D for the expansion of the angular

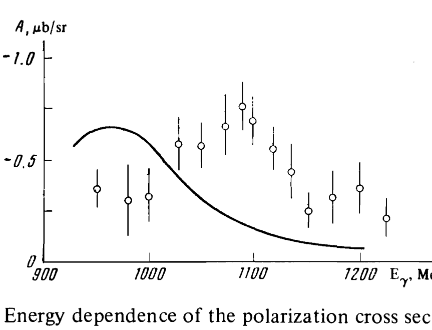

FIG. 3. Energy dependence of the polarization cross section (2). The curve was calculated with use of the amplitudes for photoproduction (1) from ref. 13.

TABLE 3.

E, MeV	A, μb/sr	B, μb/sr	C, μb/sr	D, μb/sr
950	−0.367±0.101	−0.751±0.441	0.505±0.406	5.20±2.08
1050	−0.591±0.104	−0.767±0.759	0.953±0.749	6.33±3.20
1150	−0.355±0.139	−1.818±0.762	2.96±0.90	3.27±3.24

dependence of the polarization, which are defined by the expression

$$\frac{k}{q}\frac{d\sigma}{d\Omega}P\frac{1}{\sin\theta}=A(E)+B(E)\cos\theta+C(E)\cos^2\theta+D(E)\cos^3\theta, \quad (3)$$

where θ is the π-meson emission angle in the center of mass. The coefficients for even and odd powers of $\cos\theta$ are determined by interference of the amplitudes of opposite and identical parity, respectively. If $\theta = 90°$, the left-hand side of Eq. (3) is described by the coefficient A(E), which in this case corresponds to the polarization cross sections of Table II. The values of the coefficients were obtained by fitting the angular distributions of the polarization from other studies[2-4] and the results of the present work in the form of Eq. (3).

It should be noted that the existing experimental data on angular distributions of polarization do not provide a complete representation of the nature of the energy dependence of these coefficients and do not provide the possibility of obtaining with sufficient accuracy the coefficients C and D, which may have a substantial value in the third resonance region. Therefore it is necessary to have more systematic studies of the angular dependence of the proton polarization for photon energies above 900 MeV with high accuracy and an energy resolution $\Delta E_\gamma \sim \pm 15$ MeV for the purpose of bringing to light possible structure in the energy dependence of the coefficients B, C, and D.

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