Polarization of the Proton from the $\gamma+n \rightarrow p+\pi^-$ Reaction*

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The polarization of the proton from the $\gamma+n \rightarrow p+\pi^-$ reaction in deuterium has been experimentally measured at 90° in the center-of-mass system for photon energies near 715 MeV by using a counter technique to observe the left to right asymmetry in the scattering of the protons from carbon. A value of -0.26 ± 0.06 was observed, with the direction of the polarization defined by $\hat{n}=(\hat{k}\times\hat{q})/|\hat{k}\times\hat{q}|$, where $\hat{k}$ and $\hat{q}$ are, respectively, unit vectors in the directions of the photon momentum and the pion momentum. The result is interpreted as an indication that the interference between the $P_{3/2}$ (325 MeV) and $D_{3/2}$ (750 MeV) resonances may not be the dominant contribution to the polarization at this energy. Significant contributions from either an interference between the $P_{3/2}$ (325 MeV) resonance and the possible new resonance suggested by the π, p scattering measurements, or an interference between the $D_{3/2}$ (750 MeV) and $F_{5/2}$ (1050 MeV) resonances, or a combination of these two possibilities seem to be required.

I. INTRODUCTION

INVESTIGATION of the polarization of the recoil protons accompanying the single photoproduction of pions is of interest in the study of the pion-nucleon system. As long as the reaction can be described by a transition matrix which is a sum of the contributing multipole transitions, each with given values of total angular momentum, parity, and isotopic spin, there is polarization of the proton only when at least two different states are present. In addition, the polarization of the proton is absent for protons emitted at 90° in the center-of-mass system if two states with the same parity are present. Thus, the experimental measurement of the polarization of the protons from the $\gamma+p \rightarrow p+\pi^0$ and $\gamma+n \rightarrow p+\pi^-$ reactions may provide information which is useful in the determination of the relative parity of the interfering states.

Extensive studies of the polarization of the recoil proton from the $\gamma+p \rightarrow p+\pi^0$ reaction at 90° in the center-of-mass system have been made during the past four years.[1–5] These measurements have shown that the polarization for this reaction is large in the 550–910 MeV photon energy interval. The large polarization observed for photon energies between 550 and 750 MeV has been interpreted as arising from an interference between the first (325-MeV) resonance and the second (750-MeV) resonance.[1–4] This information helped provide the basis for the negative parity assignment for the second resonance. The large value of the polarization observed for photon energies between 750 and 910 MeV has been interpreted as an indication that the interference between the second resonance and the third (1050-MeV) resonance is significant in this photon energy region and that the third resonance becomes important for photon energies higher than about 750 MeV.[2,5] The large polarization value at the higher photon energies is regarded as an indication that the third resonance has positive parity.

Experimental measurements of the polarization of the protons from the $\gamma+n \rightarrow p+\pi^-$ reaction have not previously been made because of the lack of a condensed neutron target. Such measurements, however, are of interest as a consistency check on the quantum number assignments which have been made for the resonances. In addition, measurement of the polarization of the protons from this reaction as a function of center-of-mass production angle might provide some information concerning the contribution which the nonresonant electric dipole S-wave transition makes to charged pion photoproduction.

We report in the present paper an experimental measurement of the polarization of the proton from the $\gamma+n \rightarrow p+\pi^-$ reaction using liquid deuterium to provide the target neutrons. The measurement was made for protons emitted at 90° in the center-of-mass system and at a photon energy in the neighborhood of 715 MeV.

II. EXPERIMENTAL METHOD

The use of deuterium to provide the target neutrons for the measurement of the polarization of the proton from the $(n,p\pi^-)$ reaction[6] presents several difficulties which do not occur in the polarization measurements of the $(p,p\pi^0)$ reaction in hydrogen. One of the problems arises from the momentum distribution of the target neutrons in the deuterium. The second difficulty is the concurrent production of protons from both the $(n,p\pi^-)$ and $(p,p\pi^0)$ reactions.

The loose binding of the nucleons in deuterium permits one to assume to a good approximation that photons of energy greater than about 200 MeV interact with essentially free nucleons. The motion of the target nucleon, however, does not permit a unique specification

* Work supported in part by the Office of Naval Research.
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[3] L. Bertanza, P. Franzini, I. Mannelli, G. V. Silvestrini, and V. Z. Peterson, Nuovo Cimento 19, 953 (1961).
[4] J. O. Maloy, G. A. Salandin, A. Manfredini, V. Z. Peterson, J. I. Friedman, and H. Kendall, Phys. Rev. 122, 1338 (1961).
[5] C. Mencuccini, R. Querzoli, and G. Salvini, Phys. Rev. 126, 1181 (1962).
[6] The $\gamma+p \rightarrow p+\pi^0$, $\gamma+n \rightarrow p+\pi^-$, and $\gamma+p \rightarrow n+\pi^+$ reactions will hereafter be denoted as $(p,p\pi^0)$, $(n,p\pi^-)$, and $(p,n\pi^+)$, respectively.

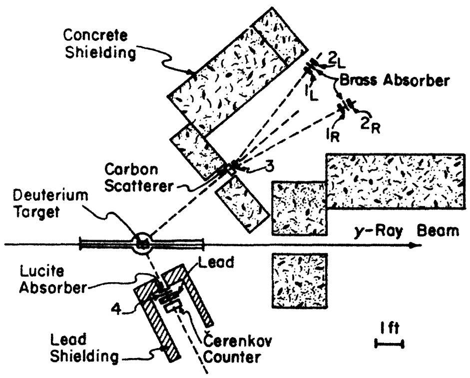

FIG. 1. Plan view of the experimental arrangement for the measurement of the polarization of the proton from the $\gamma+n\rightarrow p+\pi^-$ reaction.

of the photon energy and center-of-mass angle by a measurement of the laboratory angle and energy of the recoil proton alone. Since the polarization arises from the interference between states whose contributions may be quite dependent on the energy of the photon which initiates the reaction, measurements with target neutrons having a momentum distribution may not be the same as those which would result if stationary target neutrons were available.

We have investigated the effect which the target nucleon momentum may have on the result of the experiment by measuring the polarization of the proton from the $(p,p\pi^0)$ reaction in deuterium and comparing this result with those obtained for the same process in hydrogen. Such a comparison should give an indication as to the effect which the target nucleon motion may have on the result of the measurement of the polarization of the proton from the $(n,p\pi^-)$ reaction, since the protons and neutrons in deuterium have the same momentum distribution.

The resolution of the second difficulty required coincidence counting between the proton detectors and a meson detector sensitive only to the pion of interest in order to distinguish between protons from the $(n,p\pi^-)$ and $(p,p\pi^0)$ reactions.

The technique which we have employed for the measurement of the polarization of the protons from the $(n,p\pi^-)$ and $(p,p\pi^0)$ reactions in deuterium is similar to that used for our previous measurements of the polarization of the proton from the $(p,p\pi^0)$ reaction in hydrogen.[1] Measurement of the asymmetry in the scattering of the protons from carbon was used for the determination of the polarization. Plastic scintillation counters were used for detection of the protons. The π^- detector used in coincidence with the proton counters to define a $(n,p\pi^-)$ event consisted of a thin scintillation counter in coincidence with a Lucite Čerenkov counter. Six radiation lengths of lead were placed between the two counters, and the bias of the Čerenkov counter set so that it corresponded to a 20-MeV energy loss. Decay photons from the π^0 from the $(p,p\pi^0)$ reaction were discriminated against both by the thin scintillation counter and because the lead showered and absorbed most of the energy of the decay photons. For the measurement of the polarization of the proton from the $(p,p\pi^0)$ reaction in deuterium, a total absorption Čerenkov counter, in anticoincidence with a thin scintillation counter, was used as a detector for π^0 mesons.

A plan view of the arrangement of the experimental apparatus for the measurement of the polarization of the proton produced in the $(n,p\pi^-)$ reaction is shown in Fig. 1. An identical arrangement, except for a different meson detector, was used for the $(p,p\pi^0)$ measurement.

A bremsstrahlung beam with a maximum photon energy of 820 MeV was obtained from the Cornell 1.3-BeV electron synchrotron. After providing suitable collimation, the γ-ray beam passed through the gaps of two deflection magnets before it was incident on the liquid deuterium target. The γ-ray beam which traversed the target was monitored by means of a total absorption ion chamber (Quantameter).[7] The intensity of the γ-ray beam used for the experiment was of the order of 10^{10} equivalent quanta per minute.

Protons at 40.5° in the laboratory system were incident on the carbon scatterer. Scatterings from the carbon at 11.5° to the left and right were observed by the left and right proton telescopes. The telescope system was the same unit used in our previous measurement of the polarization of the protons from the $(p,p\pi^0)$ reaction in hydrogen.[1] All of the counters of the proton telescopes were 16 in. high and 4 in. wide. Phototubes were attached to both top and bottom ends of the scintillators. The mean pulse height of the counters for protons did not vary by more than 10% over the face of a counter. The geometrical difference between the left and right scattering angles after alignment was estimated to be less than 0.2 deg.

The minimum energy of a proton that could be counted in each telescope was 175 MeV. This range requirement, together with an 820-MeV maximum photon energy in the γ-ray beam, would have corresponded to a photon energy spectrum extending from about 620 to 820 MeV, with a mean photon energy of about 715 MeV, if a stationary target nucleon had been used. The contributing photon energy spectrum was greater than this for the deuterium measurements as a consequence of the target nucleon momentum distribution. In making our comparison of the result of the polarization measurement of the $(p,p\pi^0)$ reaction in deuterium with those from hydrogen, we have assumed that the broadening of the contributing photon spectrum was approximately symmetric and have considered that the deuterium measurement was made at a mean photon energy of 715 MeV.

[7] R. R. Wilson, Nucl. Instr. 1, 101 (1957).

The meson detection system observed pions at 63° in the laboratory system. Counter 4 consisted of a 0.01 radiation length plastic scintillator. The Čerenkov counter for the detection of pions from the $(n,p\pi^-)$ reaction was a 0.2 radiation length piece of ultraviolet-transmitting Lucite. A $\frac{3}{4}$-in.-thick piece of Lucite was put in front of counter 4 to reduce its counting rate. A $1\frac{1}{2}$-in. thickness of lead was used between counter 4 and the Čerenkov counter to shower and absorb decay photons from π^0 mesons. The aperture of the meson detection system was defined by a 4 in.×4 in. square hole in the shielding.

In the $(p,p\pi^0)$ portion of the experiment a Čerenkov counter consisting of six radiation lengths of zinc bromide was used to observe one or both of the π^0-decay γ rays. Counter 4 was used in anticoincidence with the Čerenkov counter in order to discriminate against π^- mesons from $(n,p\pi^-)$ reactions. In addition, π^- mesons were discriminated against by the bias requirement on the zinc bromide Čerenkov counter.

A hydrogen-cooled liquid deuterium target was used as a source of deuterons in the measurement. A vacuum jacket surrounded the target and extended forward and backward along the γ-ray beam line. The extension of the vacuum jacket along the γ-ray beam line removed sources of production in the air path lying directly in line with the proton asymmetry telescopes.

The left and right proton scattering events for the $(n,p\pi^-)$ reaction were given by the coincidences $\{[(1_L+2_L)+3]+(C+4)\}$ and $\{[(1_R+2_R)+3]+(C+4)\}$, respectively. Random coincidence counts were monitored by delaying the $(C+4)$ coincidences by 0.8 microsecond compared to the $[(1_L+2_L)+3]$ and $[(1_R+2_R)+3]$ coincidences. With the exception of the $(C+4)$ coincidence which had a resolving time of 20 nsec, coincidence circuits with a resolving time of 0.5 μsec were used throughout. Pulse-height distributions of the pulses from counters 1_L and 1_R which corresponded to left and right scattered proton events were recorded.

For the $(p,p\pi^0)$ measurement the left and right proton scattering events were given by the coincidences $\{[(1_L+2_L)+3]+C+(\bar{C}+\bar{4})\}$ and $\{[(1_R+2_R)+3]+C+(\bar{C}+\bar{4})\}$. [The bars in the $(\bar{C}+\bar{4})$ coincidence indicate that it was being taken in anticoincidence with the other pulses.] Random coincidence events were monitored by delaying the $C_{\rm slow}$ pulse by 0.8 μsec. Pulse-height distributions of the pulses in counters 1_L and 1_R which corresponded to left and right scattered proton events were also recorded in this case.

Biases for the counters in the detection system were set by moving the left and right scattering telescopes so that unscattered protons were observed. The counting rates for unscattered protons were measured for each telescope at the start of each asymmetry run, and were always observed to be statistically equal. The counters constituting the left and right scattering telescopes were interchanged from time to time during the course of a measurement in order to guard against inherent asymmetries which might occur in the scattering telescopes.

Table I. Left and right scattered events and the scattering asymmetry parameter after correction for random coincidences.

Reaction	Left scattered events≡L	Right scattered events≡R	$e=(L-R)/(L+R)$
$\gamma+n\rightarrow p+\pi^-$	429±21	342±20	0.113±0.038
$\gamma+p\rightarrow p+\pi^0$	519±25	322±20	0.234±0.039

Background measurements were taken at various times during the experiments when the exhaustion of the liquid hydrogen supply required the evacuation of the deuterium from the target container.

III. EXPERIMENTAL RESULTS

The experimental results for both the $(n,p\pi^-)$ and $(p,p\pi^0)$ phases of this experiment in terms of the left and right scattered events observed and the scattering asymmetry parameter, $e=(L-R)/(L+R)$, are shown in Table I. Corrections of approximately 4.5% in the $(n,p\pi^-)$ measurement and 11% in the $(p,p\pi^0)$ case have already been made for the random coincidence events, which were continuously monitored during the experiments. The uncertainties which are listed are the standard deviations due only to counting. Pulse-height distributions obtained for the scattered proton events showed good agreement, in both the $(n,p\pi^-)$ and $(p,p\pi^0)$ measurements, with the distributions obtained for the unscattered proton events.

The background measurements for the $(p,p\pi^0)$ case showed that the background contribution was of the order of 8% and approximately equal for left and right scattering. A short background measurement for the $(n,p\pi^-)$ case indicated that the background contribution for this measurement was also small. Symmetry between left and right background counts for this case was assumed on the basis of the $(p,p\pi^0)$ background results. No correction for background has been made in either case in view of the smallness and symmetry of the background contribution and the poor statistics of the background measurements.

Other reactions which might contribute in either of the measurements have been considered. In the $(n,p\pi^-)$ measurement less than a 5% contribution arose from $(p,p\pi^0)$ reactions in which π^0-decay γ rays were detected by the π^- detector. On the order of a 3% contribution in the $(n,p\pi^-)$ measurement is estimated to have resulted from $(p,n\pi^+)$ reactions in which n-p charge exchange scattering took place in the carbon scatterer. Less than a 4% contribution to the $(p,p\pi^0)$ measurement was due to $(n,p\pi^-)$ reactions in which a π^- counted in the π^0 detector. Contributions from multiple pion processes to the measurements have been assumed to be negligible on the basis of the result of the examination

TABLE II. Polarization of the proton.

Reaction	Polarization
$\gamma+n \rightarrow p+\pi^-$	-0.26 ± 0.06
$\gamma+p \rightarrow p+\pi^0$	-0.45 ± 0.06

of this question during our earlier experiment with hydrogen.[1] These contributions are all regarded as small and no corrections for them have been made.

The polarization, P, of the protons is related to the left, L, and right, R, scattering rates through the equations $L=a+bP$ and $R=c+dP$, where a, b, c, and d are quantities determined by the finite sizes of the various pieces of experimental apparatus and the range of photon energies accepted. The values of a and c and the magnitudes of b and d will not, in general, be equal as a consequence of kinematical asymmetries due to the finite sizes of the target, scatterer, and detectors. Since the scattering asymmetry parameter is given by $e=(L-R)/(L+R)$, the polarization is given by

$$P=[(a+c)e-(a-c)]/[(b-d)-(b+d)e].$$

The calculation of the polarization of the protons from the $(n,p\pi^-)$ and $(p,p\pi^0)$ reactions in deuterium from the experimentally observed asymmetry in the scattering from the carbon has been carried out using the Monte Carlo calculation for a, b, c, and d which was made for our earlier polarization measurement with hydrogen.[1] The results of that Monte Carlo calculation were $a=217$, $b=-133$, $c=238$, and $d=144$. Use of this calculation is believed to be applicable in this analysis since the present experimental arrangement was designed to be as nearly the same as possible as for the previous measurement.

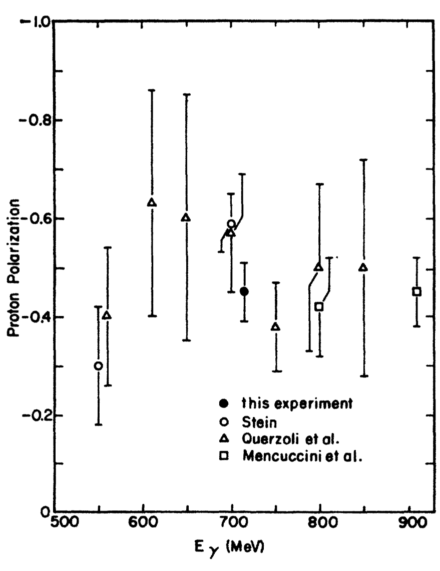

FIG. 2. Comparison of the experimentally measured polarization of the proton from the $\gamma+p \rightarrow p+\pi^0$ reaction in deuterium with results obtained from the same process in hydrogen.

The polarization of the protons from the $(n,p\pi^-)$ and $(p,p\pi^0)$ reactions in deuterium, which have been calculated from the experimentally observed scattering asymmetry, are given in Table II. The direction of the polarization is defined by $\hat{n}=(\hat{k}\times\hat{q})/|\hat{k}\times\hat{q}|$, where $\hat{k}$ and $\hat{q}$ are, respectively, unit vectors in the directions of the incident photon momentum and the pion momentum in the center-of-mass system. The uncertainties listed are the standard deviations which are obtained when only the statistics of the counting is considered.

IV. DISCUSSION

The polarization of the proton from the $(p,p\pi^0)$ reaction which we obtained in this experiment with a deuterium target is shown in Fig. 2 together with experimentally determined polarizations of the protons from the same reaction in hydrogen. The photon energy at which we have made the comparison is the mean photon energy which would contribute if the target nucleon had been stationary. Comparison of the results obtained under these different conditions seems to indicate that the polarization obtained using the deuterium target is in good agreement with the hydrogen target measurements. We have interpreted this agreement as an indication that the momentum distribution of the nucleons does not have an appreciable effect on our experimental measurement of the polarization. We, therefore, believe that our measurement of the polarization of the proton from the $(n,p\pi^-)$ reaction in deuterium may be regarded as a good approximation to the result which would be obtained for photon energies in the neighborhood of 715 MeV if a target of free and stationary neutrons were available.

TABLE III. Quantum numbers and multipole transitions for the states which have been considered as possible contributions.

Contribution	Photon energy (MeV)	Isotopic spin	Angular momentum	Parity	Multipole transition
A			$\frac{1}{2}$	$-$	$E1$
B	325	$\frac{3}{2}$	$\frac{3}{2}$	$+$	$M1$
C	750	$\frac{1}{2}$	$\frac{3}{2}$	$-$	$E1$
D	950	$\frac{3}{2}$	$\frac{3}{2}$	$-$	$E1$
E	1050	$\frac{1}{2}$	$\frac{5}{2}$	$+$	$E2$

The interpretation of the result of this initial experimental measurement of the polarization of the proton from the $(n,p\pi^-)$ reaction has been made using the table of the angular distributions and polarizations in photoproduction given by Peierls.[8] The quantum numbers and multipole transitions which have been assigned to the states which we have considered as

[8] R. F. Peierls, Phys. Rev. 118, 325 (1960).

being possible contributions are given in Table III. Contribution A represents the nonresonant direct production term. Contributions B and C are the first and second resonances. Evidence for contribution D is indicated by π, p scattering measurements.[9,10] The assignments for this state are due to Carruthers.[11] Contribution E is the third resonance seen in photoproduction.

Under the assumption that the five states indicated in Table III can contribute, the expression given by Peierls[8] for the polarization becomes, at 90° in the center-of-mass system,

$$\mathbf{P}=\frac{\mathrm{Im}(B^*A-4C^*B-4D^*B+\sqrt{3}E^*A-2\sqrt{3}E^*C-2\sqrt{3}E^*D)\hat{n}}{|A|^2+\frac{5}{2}(|B|^2+|C|^2+|D|^2)+\frac{3}{2}|E|^2+\mathrm{Re}(5CD^*-\sqrt{3}BE^*-AC^*-AD^*)}.$$

The direction of the polarization is defined by $\hat{n}=(\hat{k}\times\hat{q})/|\hat{k}\times\hat{q}|$, where $\hat{k}$ and $\hat{q}$ are, respectively, the momentum of the incoming photon and the momentum of the outgoing pion in the center-of-mass system. The amplitudes which appear in this equation are symbolic representations for any of the single pion photoproduction reactions.

If the assumption is made that the amplitudes for production of an intermediate state from protons and neutrons are the same, the amplitudes for the $(n,p\pi^-)$ and $(p,p\pi^0)$ reactions from such an isobaric state are related on the basis of isotopic spin considerations. The amplitudes for the S-wave contributions are not related to each other on this basis.

The analysis of our result for the polarization of the proton from the $(n,p\pi^-)$ reaction has been made by comparing it with the results of the more extensive measurements of the polarization of the protons from the $(p,p\pi^0)$ reaction. In order to accomplish this comparison, we have used the relations between the amplitudes for the $(n,p\pi^-)$ and $(p,p\pi^0)$ reactions given by isotopic spin conservation to write the equation for the polarization of the proton from the $(n,p\pi^-)$ reaction, except for the S-wave amplitude, in terms of the amplitudes for the $(p,p\pi^0)$ reaction. We have assumed that the S-wave contribution is negligible for the $(p,p\pi^0)$ case.

If the amplitudes for these two reactions are related in this manner, the negative value which we observed experimentally for the polarization of the proton from the $(n,p\pi^-)$ reaction is in disagreement with the assumption that the interference between the first and second resonances (C^*B) is the dominant contribution to the polarization occurring in single pion photoproduction for the photon energy interval in the neighborhood of 715 MeV. A dominant contribution from the interference between the first and second resonances (C^*B) implies that opposite signs should be observed for the polarization of the protons from the $(p,p\pi^0)$ and $(n,p\pi^-)$ reactions. Such an interpretation is, therefore, in substantial disagreement with our experimental result. It was not possible to obtain agreement with our result by only the addition of a reasonable amount of direct production term (A). We believe that our result suggests that significant contributions from either an interference between the first resonance and the possible new resonance suggested by the π, p scattering measurements (D^*B), or an interference between the second and third resonances (E^*C), or from both of these terms seem to be required. We are not able, however, to distinguish between these alternatives.

This interpretation of our experimental result does not seem to be in disagreement with the $(p,p\pi^0)$ polarization measurements. The sign of the interference between the first and second resonances (C^*B) is different for the $(n,p\pi^-)$ reaction as compared to the $(p,p\pi^0)$ reaction while the signs of the interference between the first resonance and the resonance suggested by the π, p scattering measurement (D^*B) and the interference between the second and third resonances (E^*C) are the same for both reactions. This feature thus permits our interpretation to be in agreement with the $(p,p\pi^0)$ results.

Querzoli *et al.*[2,5] have, in fact, interpreted their $(p,p\pi^0)$ polarization measurements as indicating that a contribution from the interference between the second and third resonances (E^*C) begins to be important at about 750 MeV. Our interpretation is thus substantially in agreement with theirs although we leave open the possibility that an interference between the first resonance and the resonance suggested by the π, p scattering measurement may also contribute.

It is possible that further, more refined, measurements of the polarization of the protons from the $(n,p\pi^-)$ reaction may prove interesting. If the assumption is valid that the amplitudes for production of the intermediate states from protons and neutrons are the same, one might expect to observe considerable structure in the polarization of the protons from the $(n,p\pi^-)$ reaction. In particular, at 90° in the center-of-mass system, several changes in sign of the polarization might be expected in the same photon energy range for which the polarization of the proton from the $(p,p\pi^0)$ reaction has been measured. Measurements of the polarization of the protons from the $(n,p\pi^-)$ and $(p,p\pi^0)$ reactions as functions of the center-of-mass production angle might also prove of interest. Such studies might provide an indication as to whether or not the interference between the second and third

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[10] T. J. Devlin, B. H. Moyer, and V. Perez-Mendez, Phys. Rev. **125**, 690 (1962).
[11] Peter Carruthers, Phys. Rev. Letters **4**, 303 (1960).

resonance is significant in the photon energy region of this experiment and thus possibly help to resolve the ambiguity in the interpretation of our result. A measure of the contribution that the S-wave amplitude makes in the region of the second resonance might also be obtained.

In conclusion, under the assumption that the amplitudes for the production of the intermediate states from protons and neutrons are the same, the result of our measurement of the polarization of the proton from the $(n,p\pi^-)$ reaction has been interpreted as indicating that the interference between the first and second resonances may not be the dominant contribution to the polarization for photon energies in the neighborhood of 715 MeV. Significant contributions from either the interference between the first resonance and the possible new resonance suggested by the π, p scattering measurements results, or between the second resonance and the third resonance, or a combination of these two possibilities seem to be required at this energy. These possibilities do not seem to be in disagreement with the $(p,p\pi^0)$ polarization measurements. We are not able, however, to distinguish between these alternatives.

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Low-Energy Photoproduction of Λ^0 and K^+ from Protons*

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A model is constructed for low-energy $\gamma+p\rightarrow K^++\Lambda^0$ reactions in accordance with dispersion theory by neglecting faraway singularities. Thus, besides the Born terms due to one-nucleon intermediate state and K^+ exchange, we also employ the K^* exchange and a resonance in the final state similar to that found in the reaction $\pi^-+p\rightarrow K^0+\Lambda^0$. A fairly good fit with recently measured data is obtained. [See R. L. Anderson *et al.*, Phys. Rev. Letters 9, 131 (1962).] The choice of parameters is briefly discussed.

I. INTRODUCTION

New experiments on the photoproduction of Λ^0 and K^+ from protons have recently been completed by a Cornell University group.[1] The results they obtained differ considerably from the old data.[2] The gross features of the newly measured differential cross sections in the center-of-mass system are:

(a) The K^+ meson tends to peak forward with respect to the incident photon.

(b) The angular distribution is of the form $a+b\cos\theta+c\cos^2\theta$.

(c) The excitation curve $(d\sigma/d\Omega)_{\theta=\pi/2}$ has an S-wave rise near threshold. It seems to reach a maximum around incident photon energy $E_\gamma\cong 1060$ MeV.

This "simplicity" of the existing data offers a striking contrast to its theoretical interpretations. We know that the Watson[3] theorem, which is extremely important in pion photoproduction from nucleons, cannot be applied here. This is because already in the energy range in which experimental data are available, there are many open channels: γN, $(n\pi)N$,[4] ΛK, as well as ΣK. An approach which uses dispersion integrals for partial-wave amplitudes, as has been done to many reactions, would lead to a very complicated set of coupled integral equations, and there seems to be little hope of solving them.

A number of authors[5] have discussed the possibility of applying to this problem the Cini-Fubini approximation[6] to the Mandelstam representation. They considered the contribution of the perturbation Born terms, the πN resonances, the various pion-hyperon resonances, and the $K\pi$ resonance. That no higher powers in $\cos\theta$ than 2 are required to describe the angular distribution of the K^+ meson, however, suggests the possibility of a low-energy approximation. In this

* Supported in part by the Office of Naval Research.

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[3] K. M. Watson, Phys. Rev. 95, 228 (1954).

[4] $n=1, 2, 3, 4, 5$. Although we may neglect $n>3$, $2\pi N$ seems definitely important.

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