SOVIET PHYSICS JETP VOLUME 37 (10), NUMBER 2 FEBRUARY, 1960

POLARIZATION OF RECOIL PROTONS PRODUCED IN ELASTIC SCATTERING AT 307 Mev

E. L. GRIGOR' EV and N. A. MITIN

Joint Institute for Nuclear Research

Submitted to JETP editor April 1, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 413-421 (August, 1959)

Results are presented of an investigation of the polarization of recoil protons appearing in elastic π^+-p scattering through an angle of $140 \pm 8°$ in the c.m.s. at an energy of 307 ± 5 Mev. A polarization value $P_1 = -0.19 \pm 0.17$ has been derived from the data on the magnitude of the left-right asymmetry in elastic scattering of recoil protons on photographic emulsion nuclei. Phase shifts satisfying the indicated polarization value and consistent with the differential cross section for elastic scattering of π^+-mesons by protons are given by Eq. (1).

Problems connected with the use of various phase shift sets for analysis of the experimental data are discussed.

INTRODUCTION

PHASE-SHIFT analysis of the differential cross sections for the elastic scattering of π mesons by protons leads, in general, to a whole sequence of solutions which agree equally well with the experimental results. By means of additional considerations, based on a great number of experimental and theoretical investigations of the interaction between π mesons and nucleons, it is possible to eliminate several ambiguities and to reject some of the solutions, i.e., to reduce the number of possible solutions to a minimum. As an example of this, we recall the application of the dispersion relations to meson-nucleon scattering.

There exists a direct method for a unique choice of the solution, based on phase-shift analysis of a whole set of experimental data on elastic scattering of mesons by protons, involving the differential cross sections and the polarization of the recoil protons. The polarization of recoil protons, as was shown first by Fermi,[1] is very sensitive to the values of phase shifts, and its measurement can therefore serve as a good method of uniquely choosing from among different sets of phase shifts the one compatible with the differential cross sections as well as with the polarization data.

The basic condition for the measurement of the polarization of recoil protons is the availability of an intense beam of π mesons of high energy. In this case, by scattering the π mesons at large angles, it is possible to create a sufficiently intense polarized beam of recoil protons with energy greater than 100 Mev. For this beam the effect of polarization in elastic scattering by the analyzer nuclei is great and, consequently, the magnitude of the asymmetry in scattering can be considerable.

A beam of π^+ mesons emitted from the synchrocyclotron of the Joint Institute for Nuclear Research, with an intensity of about 1,000 mesons per cm^2-sec at an energy of 307 Mev, created sufficiently favorable conditions for performing an experiment to measure the polarization of the recoil protons. The recoil protons from the π^+-p scattering, coming out at an angle of 20° in the laboratory system, had in this case an energy of 170 Mev, which was very convenient for conducting these measurements.

On the basis of the results of the phase-shift analysis previously performed by Mukhin and Pontecorvo[2] for π-meson energies of 240, 270, and 307 Mev, the expected values of polarization were calculated for the case where only the contribution of the SP-states is taken into account, as well as for the case when the contribution of the D-state is also considered. In Fig. 1 are shown the results of the calculations, made in accordance with the solutions obtained, in which the phase δ_{33} is positive and δ_{35} is negative. On the same figure are shown the results of calculations of the polarization for 307 Mev in the case when the opposite choice of signs for δ_{33}

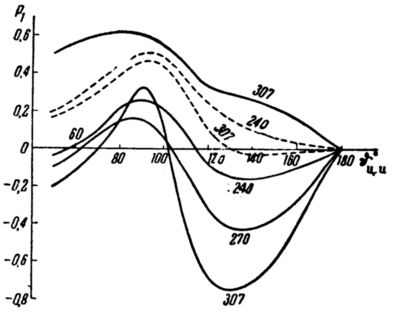

FIG. 1. Polarization of recoil protons as a function of π^+-meson scattering angle in the c.m.s. The dotted curves are for SP-analysis, the solid curves are for the SPD-analysis. The calculations were made on the basis of phase-shift sets from reference 2 for 240, 270, and 307 Mev. The upper solid curve corresponds to the set $\alpha_3 = -30°$; $\alpha_{33} = 140°$; $\alpha_{31} = -15°$; $\delta_{33} = -10°$; and $\delta_{35} = 10°$.

and δ_{35} is made. As can be seen from the figure, an important feature of the calculated curves is that relatively small values of phase shifts in the D-state significantly influence the polarization. This is especially noticeable for angles from 130° to 150°. Here the value of polarization, in the case of SPD analysis, firstly increased sharply compared to SP analysis, and secondly, changes its sign when the opposite choice of the signs of δ_{33} and δ_{35} is made. Therefore it is completely natural that the main goal of the experiment (which is to measure the polarization of the recoil protons for the angles of scattering of mesons in the interval 130° to 150° in the center of mass system) should be, first, a determination of the value of the contribution of the D state to the scattering, that is, of the values of δ_{33} and δ_{35}, and second, a determination of the signs of these phases.

There is practically no information on the contribution of the D-state to the scattering, although this question has been considered in several papers.[3] This is due to the fact that the measurements of the differential cross sections, owing to the limited precision of the results, are not sensitive enough to small values of phase shifts in the D-state. Therefore, the "optimal" sets of phase shifts in the case of SPD analysis do not permit one to draw reliable conclusions about the values of phase shifts in the D-state. Up to the present time, no polarization experiments have been made at such energies where the D-state can give a considerable effect. To determine the most favorable conditions for an experiment to measure the polarization of the recoil protons, corresponding estimates were made for π^+ mesons with energies from 200 to 307 Mev. These estimates were made by taking into account the intensities of the meson beams, the energies of the recoil protons, and the expected value of the polarization for these energies, and also by taking into account the information about the values of the differential cross sections and accuracy of their measurements. These estimates have shown that the most favorable conditions for the experiment occur at a π^+-meson energy of 307 Mev. At this energy, for a meson scattering angle of 140° in the c.m.s., (the corresponding value of the energy of the recoil proton is 170 Mev), the polarization calculated for the "optimal" set of phase shifts in the case of SPD analysis ($\alpha_3 = -13.0°$; $\alpha_{31} = -4.0°$; $\alpha_{33} = +133.7°$; $\delta_{33} = 9.5°$; $\delta_{35} = -10.0°$) was found by Mukhin and Pontecorvo to be $P_1 = -0.71$. In this case, in elastic scattering of the recoil protons by the photoemulsion nuclei, a considerable left-right asymmetry was expected, reaching a value of 0.3 or 0.4 for the scattering angles 6° and greater.

At the present time the results of only one experiment measuring the polarization of recoil protons are known.[4] In this experiment, at a π^--meson energy of 220 Mev, the polarization of recoil protons was measured for 15° and 30° in the laboratory system. Owing to major experimental difficulties, the statistical accuracy of the measurements was not good. However, based only on experimental results, an analysis of these results permits one to reject, directly, two solutions out of four and to determine precisely the sign of the phase α_1.

CONDITIONS OF THE EXPERIMENT

The setup of the experiment is shown in Fig. 2. The method of obtaining the π^+-meson beam was already described several times (see, e.g., reference 5). Mesons with energies of 307 ± 5 Mev passed through a collimator 5 cm in diameter and hit a liquid hydrogen target. The working part of the target consisted of a metallic vessel 30 cm long and 8 by 8 cm in cross section. This vessel was covered with a thick layer of foam plastic. The front and back walls of the target, through which the beam of mesons and recoil protons passed, had a rounded shape and were made of

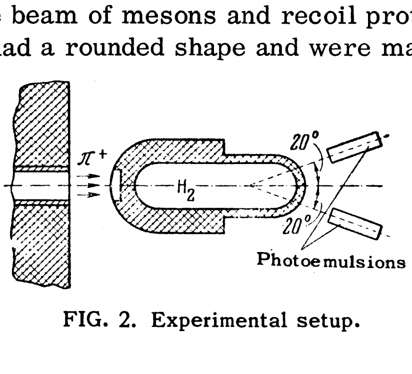

FIG. 2. Experimental setup.

brass foil 0.4 mm thick. These parts of the target were covered by a thinner layer of foam plastic, 3 cm thick. The target was placed on a special table in such a way that the axis of the target coincided very accurately with the axis of the meson beam.

The recoil protons, emitted from the target at an angle of 20°, struck photoplates placed in holders held on bars at the same angle to the left and to the right of the axis of the meson beam. The initial energy of the recoil protons was 170 Mev, but an average of 10 Mev was lost in the passage through the liquid hydrogen, the walls of the target, and in the emulsion. The emulsion played a double role, as a detector of particles and as a target for the elastic scattering of the recoil protons, that is, an analyzer of their polarization.

An investigation of background conditions showed that there were two sources of background, and it was necessary to take them into serious consideration. First was the background from the walls of the liquid hydrogen target. An estimate of this background, made by irradiating the empty target with a beam of π^+ mesons, showed it to be small, less than 1%, because in our case the working part of the target had a great length and a large cross section, and also because there was a small angular divergence of the mesons in the beam. The second background was due to the liquid hydrogen, which filled the working part of the target. This background was caused by the fact that the beam of π^+ mesons used in this experiment contained apart from a large number of protons with a momentum equal to the momentum of the mesons (the corresponding energy of the protons was $E_p = 92$ Mev), an additional number of protons with greater energy ($E_p > 150$ Mev), i.e., protons with momenta much greater than that of the mesons. The scattering of the latter protons by the hydrogen in the target produced recoil protons which could not be separated in the emulsion from the recoil protons due to π^+-p scattering. The number of high-energy protons was estimated with photoplates, irradiated in the beam of 307-Mev π^+ mesons by counting the grain density in the tracks of protons travelling along with the mesons. The measurements showed that the number of protons in the beam, with energies of 150 to 200 Mev, was not more than 2% of the number of mesons. Since the differential cross sections for emission of recoil protons (at an angle of 20° in the laboratory system) in p-p scattering are approximately equal in our case to those of the π^+-p scattering, the total background was not greater than 3%.

We searched, in this experiment, for events of elastic scattering of the recoil protons by the nuclei of the photoemulsion, in order to determine the value of the left-right asymmetry in this scattering. The search for the cases of elastic scattering was made by the method of scanning along the tracks. We chose proton tracks satisfying the following conditions: 1) The deviation of the proton tracks from the principal 20° beam direction should not be greater than ±4°, meaning a choice of recoil-proton tracks corresponding to meson scattering angles of $\vartheta = 140 \pm 8°$ in the c.m.s. 2) The dip angle of the tracks relative to the plane of the emulsion did not exceed 12°. 3) The grain density in the investigated tracks corresponded to the grain density in the tracks of 160-Mev protons. The latter density was measured in special control photoplates, irradiated by a beam of 160-Mev protons and developed each time together with the photoplates on which the search for the elastic scattering events took place. Because of the geometry of the experiment, the fulfillment of the first two conditions implied the choice of the tracks of the recoil protons which arose in a small bounded region of the liquid hydrogen target, the cross section of which was determined by the cross section of the meson beam.

Electron-sensitive emulsions of the NIKFI-R type with 400-μ emulsions were used. The scattering cases found during the scanning along the tracks were identified as elastic if the grain density in the track was the same before and after the scattering, and if there were no tracks of recoil nuclei or of electrons at the point of scattering. In each identified case of elastic scattering, the angle of scattering ϑ_p, the azimuthal angle φ, and the grain density on the sections of the tracks before and after scattering were measured. All cases of elastic scattering of recoil protons at an angle $\geq 3°$ in the plane of the emulsion were recorded; in this case, even during a brief examination of the track, the kink is very easy to see, thus disclosing the existence of scattering.

RESULTS OF MEASUREMENTS

On the photoplates, situated to the left and to the right of the axis of the π-meson beam there were found 545 cases of elastic scattering of the recoil protons by the nuclei of the photoemulsion within a scattering angle $\vartheta_p = 3.5$ to 27°, with azimuth angles $0° \leq \varphi \leq 60°$. The results of the measurements for the right and the left photoplates were correspondingly added in order to

TABLE I. Experimental results for different intervals of recoil-proton scattering angles ϑ_p and azimuth angles φ

ϑ_p, deg	$\varphi = 0$—$30°$		$\varphi = 30$—$60°$		The value of assymetry ε
	left	right	left	right	
3.5— 6	88	93	24	25	0.03 ± 0.07
6 — 9	52	63	24	25	0.08 ± 0.08
9 —13	28	32	11	15	0.12 ± 0.12
13 —27	15	22	12	16	0.20 ± 0.20

increase the statistical material. Table I lists the results, summed in such a way that all cases of scattering are considered to have taken place in the right photoplate. All cases of scattering are divided into four intervals of the scattering angle ϑ_p, each interval being in turn subdivided into two intervals of the azimuth angle φ. The asymmetry was determined for each interval of scattering angle.

It is known that in the experiments on the elastic double scattering of protons by nuclei the asymmetry ϵ is connected with the polarizations that arise in the first and second scattering through the relationship $\epsilon = P_1 \cdot P_2$. In our case P_1 is the polarization of the recoil protons from π^+-p scattering, and P_2 arises in the elastic scattering of these protons by the nuclei of the photoemulsion. It is therefore possible to determine the polarization of the recoil protons, provided the experimental values of asymmetry and of P_2 are known. The polarization of 135-Mev protons in elastic scattering by the nuclei of the photoemulsion was investigated by Feld and Maglic.[6] The results of this work were used by us to analyze our experimental results obtained in order to determine P_1.

The polarization of the recoil protons, calculated according to the data of Table I and the results of Feld and Maglic, averaged over the four angular intervals, was found to be $P_1 = -0.19 \pm 0.17$. The sign of the polarization momentum was chosen relative to the direction $\mathbf{n}$ determined by the vector product $\mathbf{n} = [\mathbf{k}_p \times \mathbf{k}_\pi]$, where $\mathbf{k}_p$ is the momentum of the recoil proton and $\mathbf{k}_\pi$ is the momentum of the π meson before scattering. The error indicated in this result is the standard deviation.

As pointed out previously, the polarization expected in our experiment, calculated on the basis on the "optimal" set of phase shifts in an SPD analysis in which the phases are $\delta_{33} = 9.5°$ and $\delta_{35} = -10°$, is $P_1 = -0.71$. The value $P_1 = -0.19 \pm 0.17$ obtained in the experiment is a great deal smaller than expected.

The most natural way to explain this discrepancy is to assume that the phase shifts of the D-states δ_{33} and δ_{35}, which determine in our case the large value of the expected polarization, are much smaller than 10°. Table II lists sets of phase shifts, which satisfy, within the limits of errors, the experimental value of polarization and are consistent with the differential cross sections of the meson-nucleon scattering. The phase shift sets are listed in the table in decreasing order of δ_{33}.

TABLE II. Phase shift sets satisfying the experimental value of the polarization

δ_{33}, deg	δ_{35}, deg	α_3, deg	α_{33}, deg	α_{31}, deg	Computed polarization	M
5	—5	—19	133.5	— 6	—0.39	5.0
5	—2	—22	132	— 8	—0.33	5.4
5	0	—21	132	— 8	—0.27	14.9
3	—3	—23	133.2	— 8	—0.27	12.7
3	—3	—25	132	—10	—0.30	11.9
2	—5	—22	132	— 8	—0.27	12.6
2	—3	—23	133.2	— 8	—0.22	11.4
2	—2	—24	133	—10	—0.23	11.7
2	—2	—23.2	133.2	— 8.4	—0.19	8.8
0	—5	—22	132	— 8	—0.16	11.8
0	0	23.2	133.2	— 8.4	—0.04	12.0

In the last column the table gives the value of

$$M = \sum_i \left[\frac{f(\alpha, \delta, \vartheta_i) - \sigma(\vartheta_i)}{\Delta\sigma(\vartheta_i)} \right]^2,$$

which characterizes the degree of deviation of the differential cross section, $f(\alpha, \delta, \vartheta_i)$, computed by phase-shift analysis from the experimental values of the differential cross section $\sigma(\vartheta_i)$. The table enables us to choose the set of phase shifts which corresponds in the best possible way to experimental polarization and differential scattering cross section data. The following set of phase shifts satisfies this condition:

$$\alpha_3 = -23.2°; \quad \alpha_{33} = 133.2°; \quad \alpha_{31} = -8.4°;$$
$$\delta_{33} = (2\,{}^{+3}_{-2})° \quad \delta_{35} = (-2\,{}^{+2}_{-3})°, \tag{1}$$

where the first three phase shifts coincide with the SP set, and δ_{33} and δ_{35} are significantly smaller than the values given by Mukhin and Pontecorvo for SPD analysis.

It is quite natural to expect the contribution of the D-states to increase rapidly for higher energies. The phase-shift analysis of experimental results[7] of elastic scattering of 500-Mev π^+ mesons has led to the conclusion that phase shifts in D-states do not exceed 10°. If we suppose, according to the results of our work, that the phase shifts of the D-states are equal to 2° at 307 Mev, and extrapolate the obtained value to high energies using the law $\delta \sim \eta^5$, where η is the relative momentum of the meson in the c.m.s., then we

TABLE III. Values of polarization P_1 corresponding to phase shifts with different signs of δ_{33} and δ_{35} phases

δ_{33}, deg	δ_{35}, deg	α_3, deg	α_{31}, deg	α_{33}, deg	P_1	M
−10	10	−30	−15	140	0,25	3.0
− 2	2	−23,2	− 8.4	133.2	0,11	12,0
− 3	− 3	−23	− 8	133.2	0,17	7.2
3	3	−23	− 8	133,2	−0.08	48.1

obtain for an energy of 500 Mev a value of 8° for the phase shifts of the D-states. This fact serves as a confirmation (though a far from sufficient one), of the correctness of the estimated values obtained in the present work for δ_{33} and δ_{35}.

The results obtained in the present work permit us to make a definite choice of the signs of D-state phases, whereby δ_{33} is positive and δ_{35} negative. As can be seen from Table III, an opposite choice of signs contradicts the experimental polarization data, since this choice would give a positive sign for the P_1. In the table this is illustrated only by two examples, but the calculations show that not one of the phase-shift sets in which δ_{33} is negative and δ_{35} positive can give a negative value of polarization and thus satisfy the experimental results. This conclusion is correct also for the case when δ_{33} and δ_{35} are both negative; one such example is given as an illustration in the third row of the table. The last case given in the table is one when both δ_{33} and δ_{35} are positive and the polarization is negative. From calculations for this case it follows that phase-shift sets in which δ_{33} and δ_{35} are both positive always give a negative polarization, whose absolute value increases with an increase of these phases. However, such phase-shift sets are incompatible in practice with the differential scattering cross section. This fact is shown by a large value of M even for the relatively small values of phase shifts for the D-states.

It has already been pointed out that the polarization determined in the experiment is significantly smaller than the expected value, calculated on the basis of the "optimum" SPD phase-shift set found by Mukhin and Pontecorvo. A possible reason for the obtained discrepancy may be the influence of inelastic processes, connected with the production of mesons by mesons, on the value of the polarization of the recoil protons in the elastic π^+-p scattering. A quantitative estimate of such an influence can be easily made by making the assumption (which is quite valid[8] up to 500 Mev) that the contribution of the inelastic processes is small and, consequently, the imaginary parts of the phase shifts are small. In this case the introduction of the imaginary parts cannot cause a noticeable change in the real parts, which already have been determined from the phase analysis. In deducing a polarization equation that takes into account the influence of inelastic processes (under the above assumption), the expansion was made only to terms linear in the imaginary part of the phase shifts. The corresponding expression for the polarization* was of the form $P = P_1 + \Delta P_1$, where P_1 was expressed only in terms of the real parts of the phase shifts and ΔP_1 contained terms linear in the imaginary parts and determined the additional polarization due to the inelastic processes. The calculation was made under the assumption that together with the main real parts $\alpha_3 = -13.0°$, $\alpha_{31} = -4.0°$, $\alpha_{33} = 133.7°$, $\delta_{33} = 9.5°$, and $\delta_{35} = -10°$, which determine the value of expected polarization, the phase shifts contain also small imaginary increments

$$\beta_3 = \beta_{31} = \beta_{33} = \gamma_{33} = \gamma_{35} = 0.02 \text{ rad.}$$

where β and γ are the corresponding imaginary parts of the phase shifts. Below are given the results of calculations for the case when only the additional polarization ΔP_1 due to the imaginary increments is computed:

The imaginary parts of the phase shifts taken into account	All phases	SP-phases only	D-phases only
The additional part of polarization ΔP_1	0.05	0.016	0.034

Therefore, when the imaginary part is equal to 0.02, the absolute value of polarization is decreased by merely 0.05, that is, instead of −0.71 it is equal to −0.66. To decrease the absolute value of polarization to 0.19 and thus agree with the mean value of the experimental result obtained under the condition that the real part of the phase remains unchanged, it is necessary that the imaginary part of all phases should be ~0.2. Such a large value is incompatible with the total cross section of the inelastic processes, which cannot, apparently, be greater than[8] 2 mb for 300 Mev, while in the case of a phase-shift with an imaginary part equal to 0.2, the cross section of the inelastic processes is significantly higher than 2 mb for each separate state that participates in the scattering. It appears therefore that it is impossible to explain the discrepancy between the expected and experimental values of polarization by a reasonable account of the influence of the inelastic processes.

*The equations for the polarization in terms of the scattering phase shifts are not given here, since they are cumbersome.

The small value of the phase shifts of the D-states for 307 Mev permits some conclusions concerning the variations of α_3 and α_{31} with the meson momentum. Assuming that the absolute values of the phases of the D-states increase rapidly with the energy, we can consider that at meson energies lower than 300 Mev allowances for the D-states have practically no influence on the values of α_3 and α_{31}. For higher energies the contribution of the D-states and their influence on the values of α_3 and α_{31} are taken into the account by assuming that δ_{33} and δ_{35} are proportional to η^5. Figure 3 shows the values of α_3 as a function of η with all these facts taken into consideration. The linear formula $\alpha_3 = -0.11\,\eta$ was proposed by Orear[9] holds up to 200 Mev, but for higher energies the experimental values of α_3, do not fit this formula even if we take into consideration large inaccuracies in the determination of α_3. It follows from the figure that at energies higher than 200 Mev $|\alpha_3|$ increases more rapidly with the meson momentum than is indicated by the relationship $\alpha_3 = -0.11\,\eta$ which, as was already stated, describes satisfactorily the experimental values of α_3 for energies below 200 Mev. In connection with this, it is interesting to remark that, in this same energy range, changes take place also in the dependence[3] of α_{33} on the meson energy. These changes consist of the fact that the experimental values of α_{33}, for meson energies greater than 200 Mev, do not fit the plot of Chew and Low, as they do for smaller energies.

The small value of α_{31} and the large relative error in its determination did not lead up to the present time to any conclusion about the variation α_{31} with the meson energy. In the work of Mukhin and Pontecorvo it was pointed out that at energies higher than 220 Mev α_{31} behaves regularly, meaning that it has a negative sign and its absolute value does not exceed 10° up to 310 Mev. It has been pointed out also that taking into the account the D-state leads to a systematic decrease of α_{31}, for example a two-fold decrease for 307 Mev. Chiu and Lomon[10] have found that the dependence of α_{31} on the momentum at energies up to 307 Mev can be satisfactorily described by the relationship $\alpha_3 = -0.91\,\eta^3$ (degrees). The phase-shift analysis in this work was done by assuming that only the SP-states participate in the scattering. This is apparently justifiable for the energies up to 307 Mev, as follows from the present work. The value of $\alpha_{31} = -8.4°$ indicated in our work also agrees satisfactorily with this relationship.

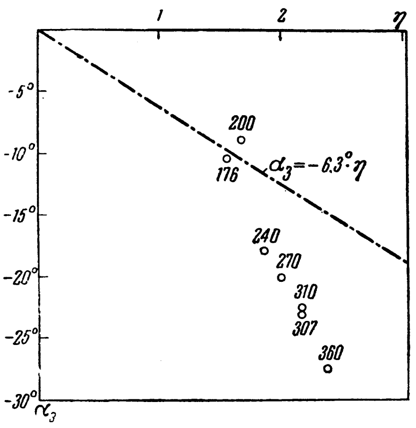

FIG. 3. Variation of α_3 with meson momentum in the c. m. s. The experimental values of α_3 are taken from the SP analysis,[3] with allowance for the corrected values of the D-state phases, obtained in the present work. The numbers denote meson energies in Mev.

All the previous discussions were concerned with the case when only phase solutions of the Fermi type are taken into account in the calculations. It is interesting to discuss the question whether or not it is possible, on the basis of the obtained experimental results, to disregard the Yang type phase shifts. Although the results of investigations[11] based on the use of dispersion relationships definitely permit the exclusion of solutions of the Yang type, one task of experimental research on polarization is to confirm this fact directly.

Table IV lists the computed values of the polarization* of recoil protons for a set of Yang type phase shifts. It can be seen in the example of the first three sets of phase shifts that whereas for the SP and SPD sets with $\delta_{33} = -\delta_{35} = 2°$ the polarization is positive, the sign of the polarization is reversed for the set in which the phase shifts of the D-state have been increased in absolute value to 10°. Estimates, on the assumption that the absolute value of δ_{33} is approximately

TABLE IV. Values of polarization computed on the basis of Yang type phase shift sets

δ_{33}, deg	δ_{35}, deg	α_3, deg	α_{31}, deg	α_{33}, deg	P_1
0	0	—23.3	298.3	156.7	0.41
2	—2	—23.2	298	157	0.27
9.5	—10	—13	297	159	—0.24
—14	5.5	—13	297	159	0.91

*In these calculations the purpose was to obtain purely qualitative results about the values and the signs of polarization, which are in a definite way determined by the values and the signs of δ_{33} and δ_{35}. Therefore, some of the phase-shift sets in Table IV may give a relatively high value of M.

equal to that of δ_{35}, show that the polarization goes through zero when δ_{33} and δ_{35} equal $\sim 5°$. The last set of the phase shifts given in the table is one for which δ_{33} and δ_{35} have respectively negative and positive signs; the polarization corresponding to this set has a large positive value. From the calculations it follows that all phase shifts of the Yang type in which δ_{33} is negative and δ_{35} is positive give a high positive value of polarization.

Thus, on the basis of experimental data on the magnitude of the polarization, the following phase shift sets of the Yang type are definitely excluded: 1) the set corresponding to the SP analysis; 2) sets corresponding to SPD analysis in which the D-state phase shifts δ_{33} and δ_{35} have respectively negative and positive signs; 3) phase shift sets in which δ_{33} and δ_{35} have respectively positive and negative signs and do not exceed 5° in absolute value. In the last case, for sets in which δ_{33} and δ_{35} have absolute values higher than 5°, the computed value of polarization may be in agreement with the experimental value.

We express our deep thanks to L. I. Lapidus for his valuable comments and numerous discussions, to A. I. Mukhin for helping in performing the experiment, to S. B. Nurushev for the discussion of results, and also to L. Mal'tseva, T. Rybakova and R. Khristova, who did much work in scanning the photo-emulsions.

We are deeply indebted to Professors V. P. Dzhelepov and B. M. Pontecorvo for constant interest and attention to our work.

[1] E. Fermi, Phys. Rev. **91**, 947 (1953).

[2] A. I. Mukhin and B. M. Pontecorvo, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 550 (1956), Soviet Phys. JETP **4**, 373 (1957).

[3] Mukhin, Ozerov, Pontecorvo, Grigoriev, and Mitin. CERN Symposium, Geneva (1956). N. A. Mitin and E. L. Grigoriev, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 445 (1957), Soviet Phys. JETP **5**, 378 (1957).

[4] Ashkin, Blaser, Burger, and Romanowski. Proc. 1958 Ann. Intern. Conf. on High Energy Physics at CERN (1958).

[5] Meshcheryakov, Zrelov, Neganov, Vzorov, and Shabudin, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 45 (1956), Soviet Phys. JETP **4**, 60 (1957).

[6] B. T. Feld, and B. C. Maglic, Phys. Rev. Lett. No. **10**, 375 (1958).

[7] W. J. Willis. Proc. 1958 Ann. Intern. Conf. on High Energy Physics at CERN, Geneva (1958).

[8] Blevins, Block and Leitner, Phys. Rev. **112**, 1287 (1958).

[9] J. Orear, Phys. Rev. **96**, 176 (1954).

[10] H. Y. Chiu and E. L. Lomon, Ann. Phys. **6**, 50 (1959).

[11] W. Gilbert and G. R. Screaton, Phys. Rev. **104**, 1758 (1956).

Translated by S. Kotz
77