pp-SCATTERING PHASE SHIFTS AT 435 MeV

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A set of phase shifts is found which satisfactorily describes the experimental data on pp scattering near 435 MeV and which agrees with the gradual energy dependence of the phase shifts deduced in [1] by interpolating between the YLAM-solution [5] and also solution 1 for energies below 310 MeV, [2-4] on the one hand, and the solution for 657 MeV [1] on the other.

WE have previously found [1] a set of phase shifts which describes satisfactorily the experimental data (obtained in Dubna) on elastic pp scattering at ~ 660 MeV, and also data on the total cross section of pion production in pp collisions. One of the features of this set of phase shifts is that it can be smoothly connected with solution 1 [2-4] at energies below the meson production threshold, and also with the YLAM solution [5] 1).

In the present paper we attempt to find a set of phase shifts describing the available experimental data on pp scattering in the energy region near 435 MeV. It is not our purpose to determine all the minima of the functional χ^2, for in view of the relative incompleteness of the present experimental information for 435 MeV the solution of this problem is unavoidably multiply valued. The search for the phase shift was therefore made in the region obtained upon interpolation between solution 1 at energies below threshold of meson production and the set of phase shifts from [1].

In accordance with the resonant model of pion production [7], it is assumed that at 435 MeV account must be taken of absorption from the initial $^3P_{0,1,2}$ and $^1D_2$ states of the pp system. The production of pions from the $^3P_{0,1,2}$ and $^1D_2$ states was described by absorption coefficients r_1 and r_2, which were averaged over j, and which were introduced in the same manner as in [1,8]; the total cross section of the $pp \rightarrow \pi^+ pn$ reaction was broken up into parts corresponding to S and P pion production, in accord with the work of Mandelstam [7].

The experimental pp interaction data used in the analysis are indicated in Table I. The phase shifts were determined by the method of least squares. The minimum of the functional χ^2 was

Table I. Data used in determination of the phase shifts at 435 MeV

Observed quantity	Energy at which the measurements were made, MeV	No. of points	Reference
$\sigma(\theta)$	435	17	[9]
$\sigma(\theta)$	437	8	[10]
P	415	8	[11]
D	415	1	[12]
C_{KP}	400	2	[13]
C_{NN}	400	2	[13]
	interpolated to		
σ_t	435		[14]
$\sigma(\pi^+ d)$	425		[15]
$\sigma(\pi^+ pn)$	437		[16]
$\sigma(\pi^0 pp)$	437		[17]

obtained with the electronic computer of the Joint Institute for Nuclear Research by the linearization method [18]. The initial formulas, the parametrization of the expressions, and the computation program were the same as previously used [1].

During the calculations, we have eliminated from the analysis the experimental values of $\sigma(\theta)$ at angles 5.1, 9.6, and 11.4°, since they differed in all cases by more than three experimental standard deviations from the calculated $\sigma(\theta)$ curve.

The phase shifts were determined for $l_{max} = 3$ and $l_{max} = 4$. The contribution to the scattering amplitude from the partial waves with $l > l_{max}$ was calculated in the one-meson approximation. The results of the calculations are listed in Table II.

The phase-shift solution for $l_{max} = 4$ was also made more precise by varying the mixing parameter $\bar{\epsilon}_2$, the value of which was found to be 0.2 ± 3.6°. The fact that the phenomenological phase shift of the $^1G_4$ wave turned out to be different from the value calculated in the one-meson approximation can apparently be regarded as an indication that at 435 MeV it is necessary to include waves

1)An analog of the solution of [1] was obtained also by Bystritskii and Zul'karneev[6].

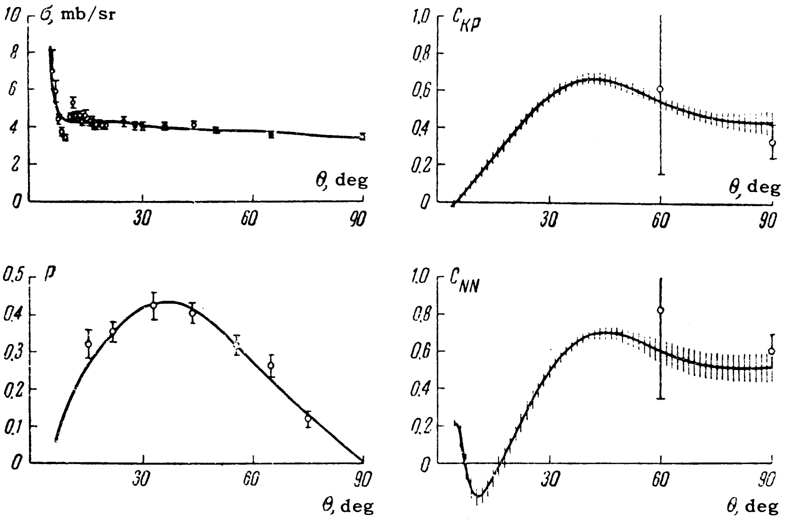

FIG. 1. Angular dependence of the differential cross section, the polarization, and the spin correlation coefficients at 435 MeV, in accordance with the phase shift set of Table II (l_{max} = 4) of the present paper. The vertical lines show the error corridor. The experimental data employed are indicated (the cross section data were taken from: o–[9]; •–[10]).

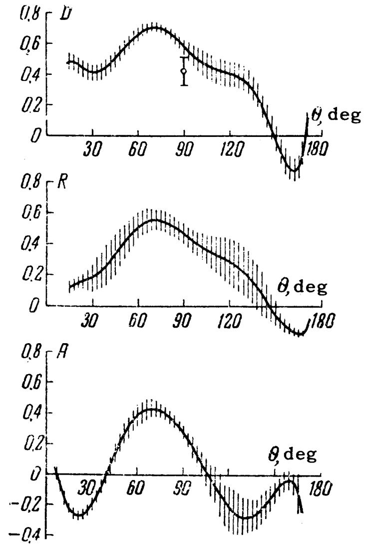

FIG. 2. Angular dependence of the triple-scattering parameters in accordance with the phase shift set of Table II (l_{max} = 4) of the present paper.

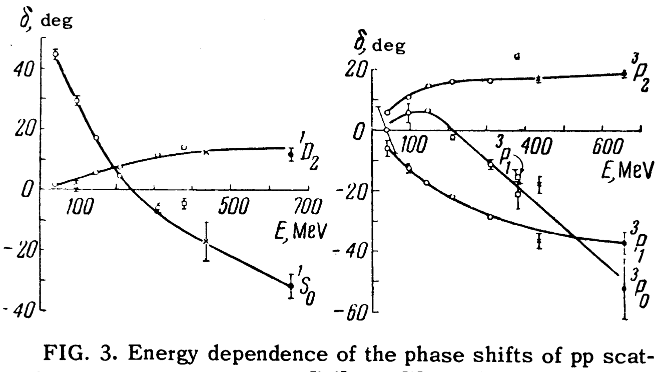

FIG. 3. Energy dependence of the phase shifts of pp scattering. ×—present work, o—[3,4]; •—[1]; □—[19]. The solid curves are drawn freehand.

with at least l = 4 in the phenomenological analysis.

The value χ^2 = 32.2 with 29 degrees of freedom

Table II. Phase shifts in degrees and the absorption coefficients at 435 MeV

	l_{max} = 3	l_{max} = 4
χ^2	32.6	32.2
$\delta\,(^1S_0)$	−9.8±2.8	−16.8±6.4
$\delta\,(^3P_0)$	−18.9±3.1	−17.7±3.1
$\delta\,(^3P_1)$	−39.0±1.3	−36.4±2.6
$\delta\,(^3P_2)$	15.1±1.0	17.2±1.4
ε_2	1.4±1.7	
$\delta\,(^1D_2)$	12.9±0.8	12.4±0.8
$\delta\,(^3F_2)$	0.5±1.0	1.9±1.3
$\delta\,(^3F_3)$	2.3±1.6	−0.4±1.8
$\delta\,(^3F_4)$	4.5±0.5	4.8±0.4
$\delta\,(^1G_4)$	1.12(OPEC)	2.3±0.9
r_1	0.990±0.003	0.990±0.003
r_2	0.936±0.007	0.936±0.007

indicates that the obtained set of phase shifts offers a statistically satisfactory description of the experimental data included in the analysis.

The angular dependences of the observed quantities, calculated from the phase shifts obtained in the present work (with l_{max} = 4), are shown together with the experimental values used in the analysis in Figs. 1 and 2.

Figure 3 shows the energy dependence of the pp scattering phase shifts. At energies below 310 MeV the phase shifts correspond to solution 1 [3,4], while the phase shifts for 657 MeV are those obtained earlier [1] and those for 380 MeV were obtained by Kazarinov et al [19]. The solid curves were drawn freehand. It is seen that the phase-shift solution obtained for 435 MeV agrees well with the curves which join smoothly solution 1 for energies below 310 MeV and the solution for 657 MeV. It is interesting to note that the energy dependence of the phase shifts of nucleon-nucleon scattering from 0 to 400 MeV, calculated by Scotti and Wong [20] with the aid of relativistic dispersion relations, yields for 400 MeV pp-scattering phase shifts that are close to those obtained in the present work. The energy dependences of the pp scattering phase shifts given by Scotti and Wong [20] agree qualitatively with those indicated in Fig. 3.

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