PHASE-SHIFT ANALYSIS OF pp-SCATTERING AT AN ENERGY OF 150 Mev

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A nine-parameter phase-shift analysis (in which the single meson "tail" is taken into account) is applied to the experimental data on 150 Mev pp-scattering (the cross section, polarization, depolarization and rotation of polarization) by aid of a new numerical method (the "ravine" method). Two distinct solution regions are obtained, which are similar to those previously obtained for an energy of 95 Mev. The solution found by Stabler and Lomon[6] lies in one of these regions. The results are compared with the theoretical estimates for the peripheral phase shifts.

1. RESULTS OF ANALYSIS

A new numerical method (the "ravine" method) has been successfully used for the analysis of data on pp-scattering at an energy of 95 Mev. In contrast with the generally used "local" method, this new method makes it possible to find the possible values of the scattering phases with great accuracy.[1] In the same paper, analysis was similarly carried out of data on pp-scattering at 142 — 147 Mev; data on the cross section $\sigma(\theta)$ and polarization $P(\theta)$ for 17 angles of scattering[2*] together with data on the depolarization $D(\theta)$ for 5 angles[9] and on the rotation of the polarization $R(\theta)$ for 8 angles.[4]

As independently variable parameters, characteristic phases were selected with account of Coulomb interaction $\delta_0(^1S_0)$, $\delta_2(^1D_2)$, $\delta_1^0(^3P_0)$, $\delta_1^1(^3P_1)$, $\delta_1^2(^3P_2)$, $\delta_3^3(^3F_3)$, and the matrix elements

$$\xi_2 = \mathrm{Re}\,[S^2_{1,3}/2i], \qquad \eta_3^2 = \mathrm{Re}\,[(S_3^2 - e^{2i\Phi_3})/2i],$$
$$\eta_3^4 = \mathrm{Re}\,[(S_3^4 - e^{2i\Phi_3})/2i]$$

($S^J_{J-1,J+1}$, S^J_l is the scattering matrix with account of Coulomb interaction, Φ_3 is the Coulomb F phase). Here, just as in the analysis for 95 Mev,[1] it was assumed that

$$\mathrm{Im}\,[(S_3^4 - e^{2i\Phi_3})/2i] = 0,$$

and all higher matrix elements were taken into account in the single-meson approximation.

As a result of the analysis, two distinct solution regions were obtained, which lie within the limits shown in the table. The limits for region I are indicated by the criterion $\chi^2 \le 2\overline{\chi^2}$ ($\overline{\chi^2} = 38$ is the mean mathematical expectation), while for region II, which has a larger value of χ^2, the limits are indicated by the criterion $\chi^2 \le 3\overline{\chi^2}$.

The inclusion of data on $R(\theta)$ played an important role in obtaining the comparatively narrow separated regions. Analysis without these data leads to a much broader range of solutions such as the region obtained in analysis of the data on 95 Mev.[1] Data are also given in the table for two points from regions I and II: the points 1, 2 and 4, 5, respectively; The curves $D(\theta)$, $R(\theta)$ and $A(\theta)$ corresponding to these points are shown in Figs. 1 — 3. More recent, more accurate data,[5] containing additional measurements at angles of 12, 21, and 31°, are plotted in Fig. 1, along with the experimental points used by us in the analysis.[3] We have not plotted the curves for the cross section and polarization, since the different solutions practically coincide within the limits of experimental error.

Analysis was also carried out with data on depolarization obtained at Harwell (cited by Hwang et al.[3] and indicated by the dashes in Fig. 1). This change of data leads only to a certain shift in the regions and to an increase in the values of χ^2. Data for single points of regions I and II (3 and 6, respectively), which were obtained with the changed data, are given in the table. It is interesting to note that we did not succeed in obtaining solutions with larger negative values of the polarization at angles $\theta \approx 70°$.

As has already been pointed out earlier,[1] regions I and II are analogs of the corresponding regions I and II found for 95 Mev, while according

*The data of Palmieri et al.[12] for angles of 18.7, 22.8, 24.9, 46.5° and also $\theta \le 8.3°$ and $\theta \ge 92°$ were not taken into consideration in determining the square deviation, for the results are very sensitive to possible inaccuracies in the angles, owing to the large, rapidly changing Coulomb contribution to the cross section at small angles (4.13, 6.2 and 8.34°), and the remaining data furnish practically no added information.

Limits of regions of solution and certain solutions

Phase shifts	Limits of region I	Points 1	Points 2	Points 3	Limits of region II	Points 4	Points 5	Points 6
χ^2	$\leqslant 2\overline{\chi^2}$	37	82	62	$\leqslant 3\overline{\chi^2}$	58	68	70
$^1S_0$	11—23	16.9	15.9	16.2	—35——6	—8.8	—26.8	—14.5
$^1D_2$	5—9	7.7	6.8	7.6	3—10	8.0	6.4	7.7
$^3P_0$	1—11	7.6	5.0	11.8	—30——20	—23.8	—22.2	—25.1
$^3P_1$	—20——15	—16.9	—18.2	—18.0	2.5—9.5	5.2	8.7	7.3
$^3P_2$	14—17	16.0	16.3	15.2	14—20	18.4	15.6	17.5
ξ_2	—3.5——1	—1.9	—2.5	—2.9	—5.5——0.5	—4.6	—0.8	—4.0
$\eta^2{}_3$	—2.5—1.5	—1.4	1.7(T)	—0.9	—3.5—1	0.4	—0.3	—0.5
$^3F_3$	—1—4	1.1	—1.1(T)	0.7	—2.5—2.5	—2.0	2.5	—1.9
$\eta^4{}_3$	—0.5—1.5	—0.08	0.9(T)	0.7	—1—1	—0.4	—0.06	—0.02

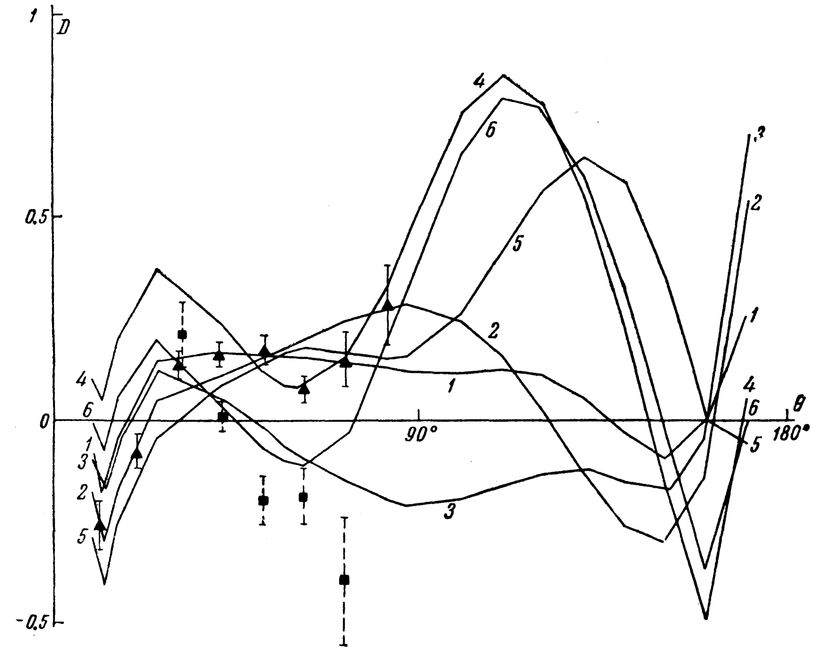

FIG. 1

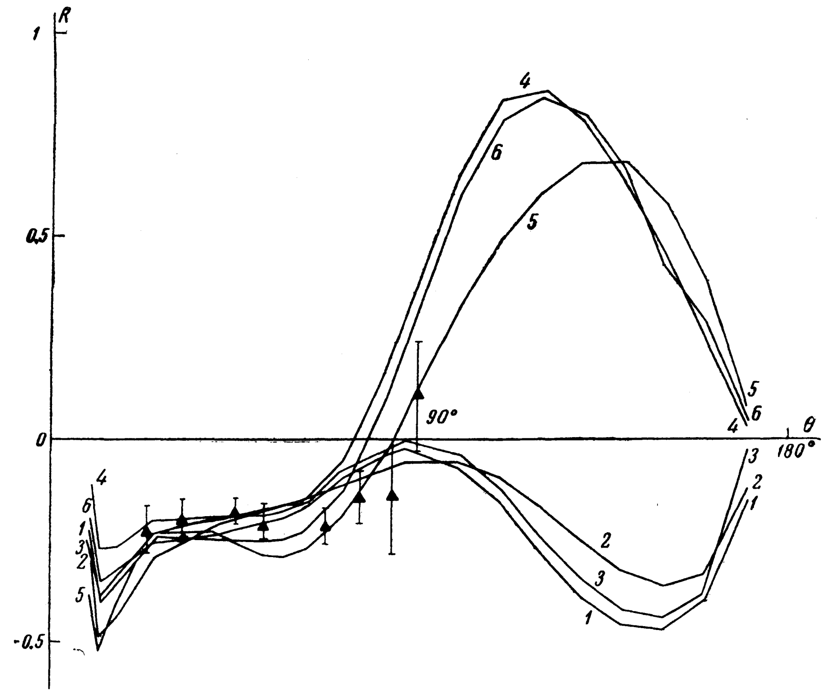

FIG. 2

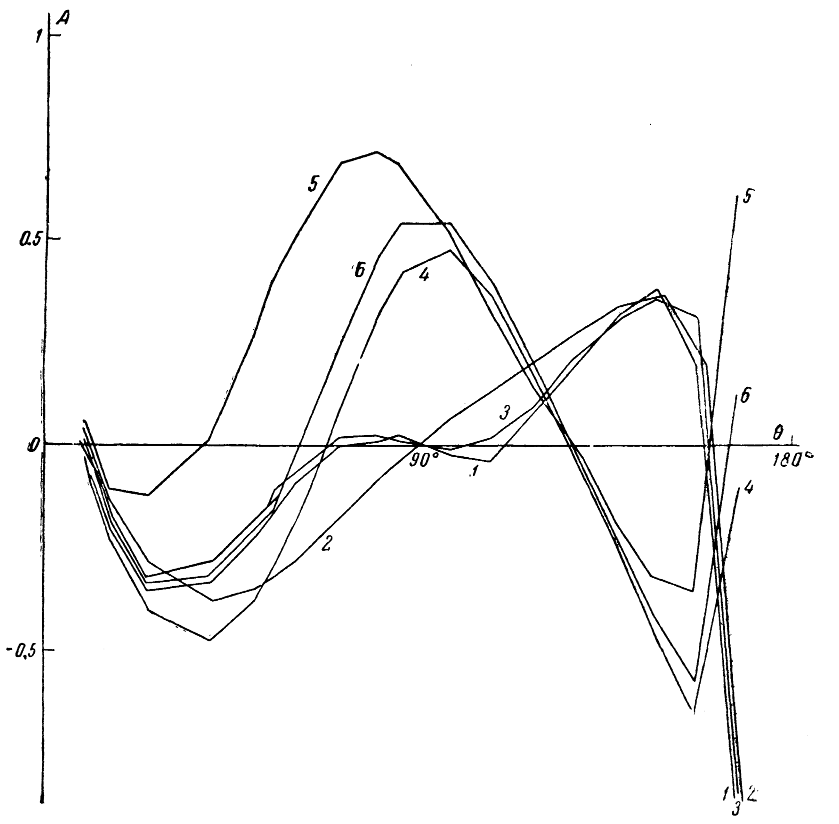

FIG. 3

to the values of the ^1S phase the region I is to be preferred. The solution found by Stabler Lomon[6] lies in the first region, but the tolerances for the possible values of the phase, which they derived, by means of the error matrix are far too low.

2. COMPARISON WITH THEORY

For energies of 150 Mev, the D and F phases and the mixing parameter can be regarded as "weakly peripheral," since the interaction in the corresponding states effectively takes place at distances $r_{eff} \approx 1.5/\mu$ (μ is the mass of the π meson). The single-meson approximation gives a value of $\delta_2 = 3.3°$ for the ^1D phase (δ_2 is the sum of the purely nuclear and pure Coulomb phases); the estimate $\Delta\delta_2 = 1°$ is obtained for the two-meson correction. The results of the analysis show that the two-meson phase shift obtained previously[7,8] gives the correct sign and order of magnitude for the correction to the single-meson phase shift. If the contribution from the next peripheral order of approximation (3-meson, and so forth) is unimportant, then the conclusion can be drawn that the 2-meson phase evidently exceeds the obtained estimate by several fold. Preliminary, more accurate theoretical estimates also agree with this conclusion; they show that a contribution to the D phase is obtained from a rather broad region of integration over the momentum transfer t beyond the closest singularity $t = 4\mu^2$. In this region, the compensation[7,8] in amplitudes, which is characteristic for the point $t = 4\mu^2$, is partially disrupted; therefore, the method used previously (removal of the amplitudes from under the integral at the point $t = 4\mu^2$) can lead to a somewhat lower result.

To explain the role of the F phase and the mixing parameter ξ_2, three additional variants of the analysis were carried out in which: 1) these phases were "fixed" in the single-meson approximation, like the higher phases, 2) the mixing parameter was varied in comparison with the previous variant,* 3) all phases, beginning with F, and ξ_2 were assumed to be equal to zero. In the first and second variants, it was not possible to obtain solutions with χ^2 less than 150. In the second variant, points were obtained for the first region with $\chi^2 \approx 2\overline{\chi^2}$, one of which (point 2) is shown in the table, while for the second region only points with $\chi^2 \approx 120$ were obtained.

The results of the analysis thus show that these phases are important for the analysis of the data at hand, while for the solution I the deviation from the single-meson approximation is important only in the mixing parameter, and amounts to 20 — 80

*In variants 1) and 2), the two-meson correction was taken into consideration for the $^3F_4$ state.[8]

percent; for solution II, on the other hand, the corrections to the single-meson F phase and the possible single-meson values of the mixing parameter are important. If solution I is true, and the three-meson and higher peripheral contributions are unimportant for the tensor forces which make a contribution to the mixing parameter, then it follows that the two-meson approximation exceeds the estimate obtained earlier by a factor 10 — 50.[8] Such a conclusion requires more detailed investigation, since the authors do not see now any possibility for such a large increase in the previously obtained estimate. In this connection we note that for the mixing parameter we lack the compensation of the contributions of perturbation theory and the dispersion terms, which is characteristic of all the remaining phases in the region of integration over the transferred momentum $t \approx 4\mu^2$; in other cases, this compensation can serve as the source of a decrease in estimates in the use of the "peripheral" method (see references 7 and 8). For a clarification of this contradiction it is also desirable to improve the experimental data so as to obtain more accurate phase-shift analyses. In this case, data on D and R at angles of $\theta \gtrsim 90°$ are important for unambiguous choice of solution.

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