PHASE ANALYSIS OF *pp*–INTERACTION AND COMPARISON OF *NN*–AND *pC*–SCATTERING AT 660 MeV

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The experiments performed in Dubna with *pp*-scattering in the energy range from 610 to 660 MeV include measurements of the differential cross sections, the polarization, the triple scattering parameters D, R and A, and the spin-correlation coefficients C_{kp} and C_{nn}. Along with this experiments, in which the inelastic processes $pp \to \pi^+ d$, $pp \longrightarrow \pi^+ pn$, and $pp \longrightarrow \pi^0 pp$ were studied, were carried out in the same energy range.

The combined results (50 values of the observed quantities) underwent a phase analysis in the approximation of the resonance model of pion formation in *pp*-collisions and were also used for a direct reconstruction of the *pp*-scattering matrix.

The most recent, corrected version of the phase analysis, which was carried out with allowance for new data on the angular dependence of the triple-scattering parameter A, showed that the available experimental results can be statistically represented in a reliable way ($\chi^2/\overline{\chi}^2 = 0.90$) by a set of the real parts of the phase shifts and mixing parameters (in degrees)

$\delta(^1S_0) = -32.0 \pm 5.5$; $\delta(^3P_0) = -58.7 \pm 8.4$;
$\delta(^3P_1) = -34.1 \pm 4.3$; $\delta(^3P_2) = 19.3 \pm 3.4$;
$\overline{\varepsilon}_2 = -3.6 \pm 2.8$; $\delta(^1D_2) = 8.7 \pm 4.9$;
$\delta(^3F_2) = -5.0 \pm 1.3$; $\delta(^3F_3) = 2.0 \pm 1.9$;
$\delta(^3F_4) = 1.8 \pm 0.7$; $\overline{\varepsilon}_4 = -5.4 \pm 1.4$;
$\delta(^1G_4) = 6.7 \pm 1.4$; $\delta(^3H_4) = 0.4 \pm 0.7$

and the absorption coefficients averaged over the total angular momentum J: $r\ (^3P_{0.12}) = 0.536 \pm 0.022$; $r(^1D_2) = 0.678 \pm 0.037$, and $r(^3F_{2,3}) = 0.795 \pm 0.020$ [1]. A similar phase solution was also found by other authors [2, 3], who analyzed the same experimental results.

It should be emphasized that the existing experimental information on elastic *pp*-scattering near 660 MeV can be described by means of a s i n g l e phase solution. The most probable set of phase shifts can be as shown in Fig. 1. These are closely related to the corresponding curves of the YLAM-solution of Breit et al. [4] and to the phase shifts calculated by Kazarinov and Silin [5] for energies below 340 MeV. Using the curves thus plotted, which describe the energy dependence of the phase shifts in the interval from 340 to 660 MeV, it is possible, as was shown by L.Azhgirei [6], to satisfactorily reproduce the existing data on *pp*-scattering at 435 MeV. The results of measurements recently performed by Roth et al. [17] on the parameters P, D, R, A, and A' in *pp*-scattering at 430 MeV are also in good agreement with the set of *pp*-scattering phase shifts found by Azhgirei.

The level, which the experimental investigation of *pp*-scattering near 660 MeV has reached in Dubna and the phase analysis of the results obtained enable us to draw some conclusions with regard to the pp-interaction in the region of single pion formation.

1. Over the energy interval under consideration the $^1S_0$-phase shift decreases monotonically, reaching a value of $-32°$ at 660 MeV. This definitely indicates that at high energies strong repulsion forces occur between two protons in the $^1S_0$-state at short distances from one another. Noteworthy is the fact that the energy-dependence of the $^1S_0$-phase is reproduced up to 660 MeV by the effective-radius formula modified by Noyes [8].

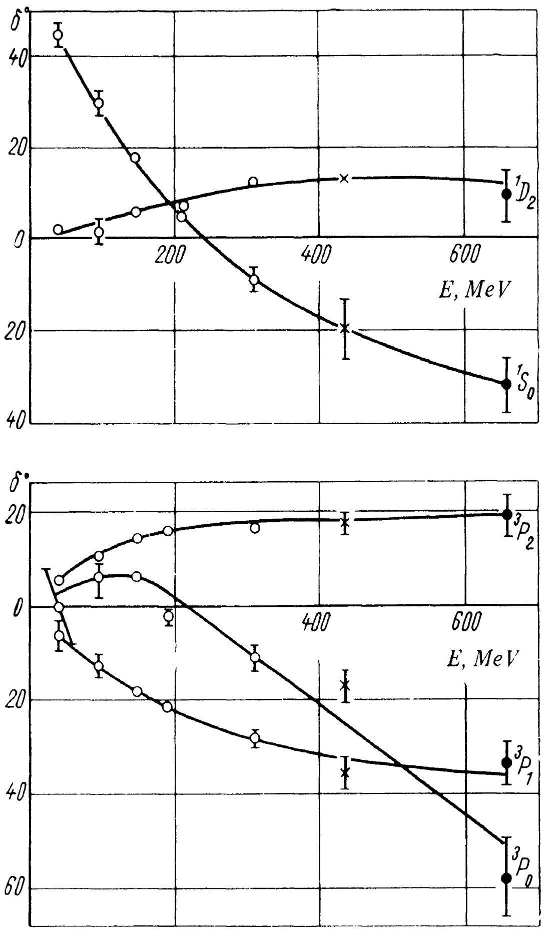

Fig.1. Energy dependence of the phase shifts of pp-scattering:

● – according to data of [1]; ○ – according to data of [5]; × – according to data of [6]. The solid curves are plotted visually below 345 MeV and coincide with the YLAM-solution [4].

The energy dependence found for the $^1S_0$-phase shift may be interpreted, as shown by Otsuki et al. [9], on the basis of the assumption that the proton has a core of finite height (of the order of several billion electron volts) with a sharp boundary. Such a core should give rise to short-range LS-forces of the Thomas type.

2. Near 660 MeV the $^3P_0$- and $^3P_1$-phase shifts are negative, whereas the $^3P_2$-phase shift is positive. The splitting of the ^3P_J-phase shifts at 660 MeV fairly well satisfies the well-known interval rule, which holds only in the Born approximation for a mixture of central and LS-forces [2]. This, as well as the fact that the "spin-orbital" amplitude in the pp-scattering matrix is dominant, suggests that near 660 MeV pp-interaction in ^3P_J-states is largely due to short-range forces of the LS-type, which were earlier introduced in the phenomenological potential models of NN-scattering in the nonrelativistic domain. However, a similar conclusion cannot be drawn with regard to pp-interaction in ^3F_J-states, since at 660 MeV the ^3F_J-phase shifts are extremely small (this is particularly true for the $^3F_4$-phase shift) and do not display LS-splitting. The situation near 660 MeV is as if the LS-forces act over such a short range that they appear only in ^3P_J-states, but are already suppressed in ^3F_J-states.

3. The values found for the absorption coefficients indicate that absorption in the $^1D_2$-, $^3F_2$-, and $^3F_3$-states is considerably stronger than in lower ^3P_J-states. This property of the phase solution may be interpreted as an indication that the formation of pions in pp-collisions at 660 MeV mainly takes place not in the region of the repulsive core,

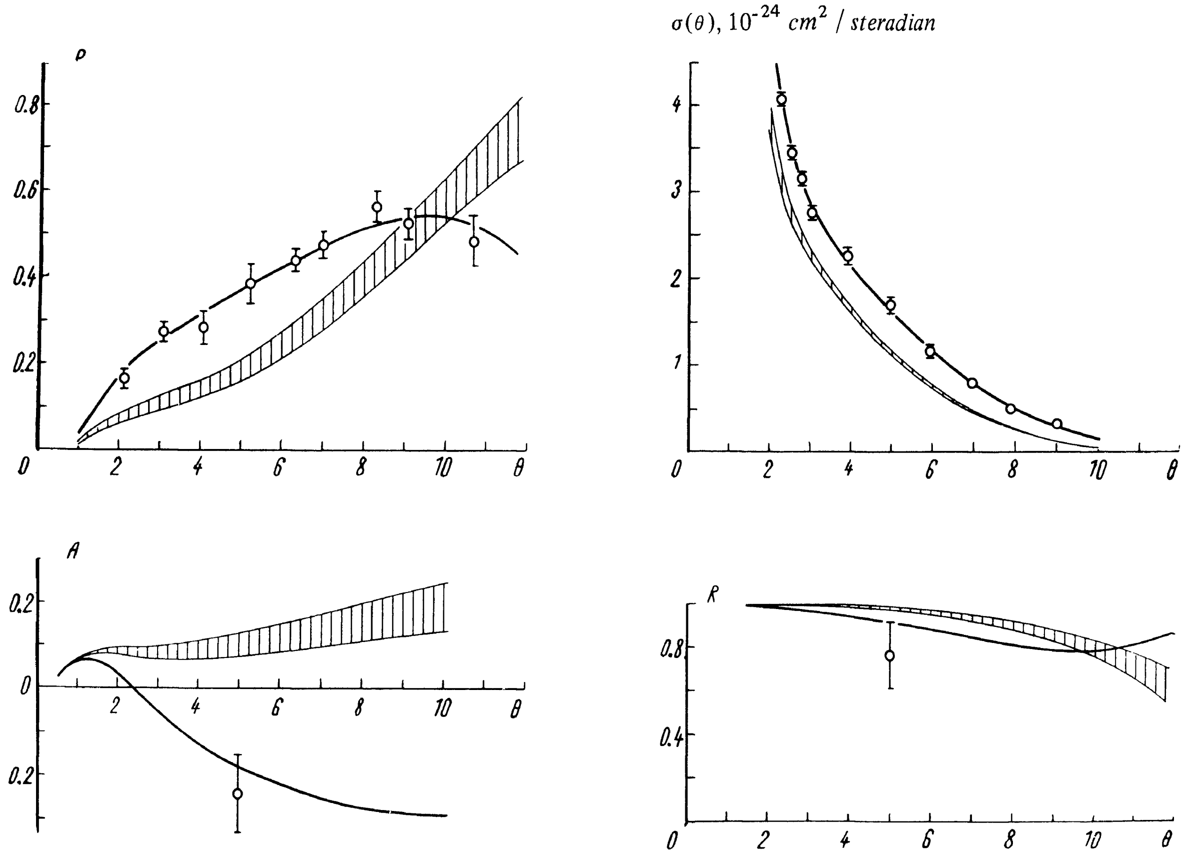

Fig.2. Angular dependence of the parameters of proton scattering on carbon nuclei at 660 MeV [the solid curves represent the result of analysis of experimental data [11]; the shaded strips represent the result of calculations from NN-scattering phases (set 1 [10])].

but in the peripheral region, where pion exchange processes play a significant role.

It should be emphasized that a phenomenological analysis of the available experimental data on pp-scattering on 660 MeV made it possible to establish only the g r o s s p r o p e r t i e s of the energy-dependence of the $T = 1$ phase shifts of the lowest states ($^1S_0$, ^3P_J, $^1D_2$) of the nucleon-nucleon system.

As regards the finding of the phase shifts for the $T = 0$ states near 660 MeV, this problem was considered by Kazarinov and Kiselev [10], who performed a joint phase analysis of the pp- and np-scattering at the above energy and found three approximately equally probable phase solutions with respect to the χ^2-criterion.

In this connection it was of interest to compare the results of the analysis of NN- and pC-scattering. A comparison was made of the Born amplitudes of pC-scattering, calculated on the one hand from the found sets of phase shifts [10] and on the other from the known values of the optical potentials of the pC-scattering.

Fig. 2 gives the results of a joint phase analysis of pp- and np-scattering at 660 MeV. They do not agree with the parameters of pC-scattering, whereas at 310 MeV such an agreement is observed.

The discrepancy between the results of the analysis of NN- and pC-scattering at 660 MeV may be considered as largely due to the small amount of experimental information on np-

scattering in this energy range.

The next step toward a more accurate determination of the phase shifts at 660 MeV, particularly of higher states, requires both further experimental investigations of the *NN*-interaction in the energy range under consideration, and a more systematic allowance (along with the one-pion-exchange diagrams) for diagrams corresponding to the exchange of vector and scalar pion systems.

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