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R.Ya. Zul'karneev, I.N. Silin

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PHASE SHIFT ANALYSIS OF ELASTIC (pp)-SCATTERING AT 660 MEV

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Abstract

The phase shift analysis of 660 MeV elastic pp – scattering has been performed. One set of phase shifts has been obtained in the interval $\overline{\chi}^2 \leq \chi^2 \leq 2\overline{\chi}^2$ and four sets have been obtained in the interval $2\overline{\chi}^2 \leq \chi^2 \leq 3\overline{\chi}^2$. The curves, calculated on the basis of the most probable phase shift set, for the angular dependence of the values $\sigma(\theta)$, $P(\theta)$, $C_{nn}(\theta)$, $C_{kp}(\theta)$, $D(\theta)$, $R(\theta)$ and $A(\theta)$, are given .

The phase shift analysis of NN - interaction at energies higher than the pion production threshold is of great interest.

In this energy range the most detailed study of pp-scattering at about 660 MeV was performed, where a large programme of experimental investigation of elastic and inelastic pp-interaction was carried out at the Dubna synchrocyclotron. Many peculiarities of the analysis of inelastic interaction at 660 MeV found their reflection in the Mandelstam resonance model /1/ according to which pion production occurs only in a small number of states. Therefore, it is reasonable to make use of this model indications and to take into account pion production only in $^1D_2$ and $^3P_{0,1,2}$ -states in making the phase shift analysis. Under this assumption a number of performed experiments on elastic pp-scattering prove to be adequate for carrying out a phase shift analysis.

Below there are given the results of the performed phase-shift analysis which permits, on the one hand, to see the picture of elastic pp-interaction in various spin states far from pion threshold, and on the other hand, to get indications for further planning 660 MeV pp-scattering experiments.

The present analysis is similar in many respects to the Kazarinov and Silin works /2,3/ . The account of the one pion exchange contribution to the scattering amplitude is made by the formulas of refs. /2,3,4/ with the pion-nucleon interaction constant equal to 0.08. The value of the orbit moment ℓ_{max}, above which scattering may be described by a one-pion Feynman graph, was determined according to ref. /5/. At the time it was found that $\ell_{max} = 4$.

In the phase shift analysis the data of papers for differential cross section $\sigma(\theta)$ /6,7/ (12 points); the polarization $P(\theta)$ (14 points) /8/; the parameters $D(\theta)$ /9/ and $R(\theta)$ /10/ (10 points); $C_{nn}(\theta)$ /11,12/ (3 points); $C_{kp}(\pi/2)$ /13/ and the values of the total cross section of pp-scattering for 660 MeV /14/ were used.

The parametrization of paper /15/ was taken in which phase shifts and mixing coefficients should be considered complex for the inelastic region. It was also assumed that $\bar{\delta}_\ell \equiv \bar{\delta}_\ell^R + i\bar{\delta}_\ell^I$ for singlet transitions; for triplet transitions with $\ell = j$: $\bar{\delta}_{\ell,j} \equiv \bar{\delta}^R_{\ell,j} + i\bar{\delta}^I_{\ell,j}$ and for the transitions with $\ell = j \pm 1$:

$$\bar{\delta}_{j\pm 1,j} \equiv \bar{\delta}^R_{j\pm 1,j} + i\bar{\delta}^I_{j\pm 1,j}$$

$$\epsilon_j \equiv \epsilon_j^R + i\epsilon_j^I$$

where due to the unitarity of S-matrix $\bar{\delta}^I \geq 0$.

In accordance with the Mandelstam model near 660 MeV the phase shifts $^1D_2$, $^3P_{0,1,2}$ -states were taken to be complex, while the imaginary phase shifts $^1S_0$, $^3F_{2,3}$ -states and the parameter were considered to be equal to zero. The value earlier obtained by Soroko /16/ and equal to 18.24° was used for $\bar{\delta}^I(^1D_2)$.

The phase shifts were found by the least-squares method. The search for the minimum of the functional χ^2 was made by the linearization method /17/ with the help of an electronic computer of the Joint Institute for Nuclear Research. After more than 100 searches (with $\ell_{max}=4$ and $\bar{\chi}^2=28$) in the interval $\bar{\chi}^2 \leq \chi^2 \leq 2\bar{\chi}^2$ one solution (phase shift set No I; $\chi^2 = 47$) was found, and in the interval $2\bar{\chi}^2 \leq \chi^2 \leq 3\bar{\chi}^2$ -four solutions with $\chi^2 =$ 62.1; 67.2; 82.7 and 83.1 (sets 2,3,4 and 5, respectively). The phase shift sets obtained thus are given in Table I. Figs. 1,2,3 illustrate the angular dependence of experimentally measured values calculated with the help of phase shift set I.

In order to clearify the stability of solution No.I and to check the correctness of assumptions taken in the analysis solution 1 was defined more exactly with the additional variation of the following pairs of the parameters $\bar{\delta}^I(^1S_0)$ and $\bar{\delta}^I(^1D_2)$; $\bar{\delta}^I(^3F_2)$ and ϵ_2^I ; $\bar{\delta}^I(^3F_2)$ and $\bar{\delta}^I(^3F_3)$ with $\epsilon_2^I = 0$. As a results, with a practically constant value of the criterion of fitness $\chi^2/\bar{\chi}^2 = 1.5$ a good evidence of the above conditions was obtained, while $\bar{\delta}^I(^1D_2)$

turned out to be equal to (14.3 ± 4.3)°. No great change of $\chi^2/\bar{\chi}^2$ even with the increase of ℓ_{max} from 4 to 5 was found.

The results of these tests show on the one hand, that if there is a reduction of the number of taken parameters, it is negligible. On the other hand, the fact that the criterion $\chi^2/\bar{\chi}^2$ remains constantly somewhat larger than unity, evidences to a probably overstated accuracy of some of experimentally obtained values.

It is of interest to note that with available accuracy of experimental data the number of solutions turned out to be small, while solution I smoothly transfers (as it will be shown in a more detailed publication) to the analogue of the first Stapp solution. In all the phase shift sets $\bar{\delta}^R\ ({}^3P_0)\ <0$, while $\bar{\delta}^I\ ({}^1D_2, {}^3P_2)$ beyond errors, differs noticeably from zero with $\epsilon_2 \approx 0$. Both the values $\bar{\delta}^R({}^1S_0)$ and $\bar{\delta}^R({}^1D_2)$ obtained in ref. /12/ for a solution – *a* for 650 MeV *pp*-scattering and $A(\frac{1}{2}\ \pi)$ predicted in /12/ agree with the values corresponding to them, given by solution No.I of the present paper.

A more definite choice of the most reliable phase shift set will be possible after the additional measurements of a number of scattering parameters at certain points.

At present we are making a more accurate analysis with the account of relativistic effects.

On completing the present work we came across paper /18/ in which its authors obtained a set of real phase shifts of elastic *pp*-scattering at 660 MeV using the averaged values of the absorption coefficients $r = \exp(-2\ \bar{\delta}^I)$ in ${}^3P_{0,1,2}$ and ${}^3F_{2,3}$ -states calculated on the basis of the Mandelstam model. The authors of the quoted paper did not take into account the contributions of one-pi on graph and the Coulomb interaction; they do not give the corridor of errors of phase shifts what complicates the quantitative comparison of the results of both the analyses.

The calculation of the criterion of fitness which we have performed for a solution obtained in /18/, has led to the values $\chi^2/\bar{\chi}^2=3$ The variation of earlier fixed imaginary phase shifts performed with the account of the contribution of the Coulomb interaction and scattering with $\ell > \ell_{max} = 4$ considerably reducing χ^2, changed sharply real phase shifts, provided large values of $\bar{\delta}^2\ ({}^3F_2)$, $\bar{\delta}^I({}^3F_3)$ and led to the negative values of imaginary parts of the phase shifts $\bar{\delta}\ ({}^3P_0)$, $\bar{\delta}\ ({}^3P_1)$. The latter disagres with the requirement of the unitarity of S-matrix. The equating phase shifts $\bar{\delta}^I({}^3P_{0,1})$ to zero would increase χ^2, making it as large as ~ 80.

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Table 1.

The values of the nuclear bar phase shifts in degrees					
Phase shifts	set 1, $\chi^2 = 47.0$	set 2, $\chi^2 = 62.1$	set 3, $\chi^2 = 67.2$	set 4, $\chi^2 = 82.7$	set 5, $\chi^2 = 83.1$
$\bar{\delta}^R(^1S_0)$	-21,2±8,5	12,8±6,8	- 8,5±6,9	18,1±5,4	-17,2±4,5
$\bar{\delta}^R(^3P_0)$	-37,7±7,4	-51,5±6,6	-23,6±4,1	-88,2±5,6	-39,5±10,1
$\bar{\delta}^R(^3P_1)$	-15,2±5,0	- 5,7±6,6	- 2,7±3,6	35,4±3,9	-39,1±4,4
$\bar{\delta}^R(^3P_2)$	56,8±9,3	45,7±2,2	-59,0±3,2	9,3±1,1	13,0±3,1
$\bar{\delta}^R(^1D_2)$	4,2±2,7	2,2±6,3	- 0,5±3,8	-1,5±4,8	- 4,9±3,3
ϵ_2^R	- 0,1±4,2	- 3,1±3,0	- 0,1±2,7	- 0,9±1,4	- 9,3±4,6
$\bar{\delta}^R(^3F_2)$	- 6,3±1,1	- 7,4±1,8	- 3,8±1,0	-14,8±1,5	5,9±2,2
$\bar{\delta}^R(^3F_3)$	3,0±1,6	- 5,5±3,1	9,8±1,0	-13,5±2,0	3,5±2,3
$\bar{\delta}^R(^3F_4)$	- 3,8±1,0	- 6,5±0,7	6,2±1,4	- 1,3±0,5	7,8±0,7
$\bar{\delta}^R(^1G_4)$	7,8±1,0	0,8±1,7	- 4,6±1,1	2,0±1,2	- 5,5±0,8
$\bar{\delta}^I(^1S_0)$	-	-	-	-	-
$\bar{\delta}^I(^3P_0)$	1,9±10,1	7,6±10,2	3,2±9,0	5,6±6,7	- 2,6±10,9
$\bar{\delta}^I(^3P_1)$	- 2,0±3,4	8,5±5,2	2,1±4,5	3,9±2,7	- 1,4±3,5
$\bar{\delta}^I(^3P_2)$	29,1 ±6,3	10,6±2,0	20,1±3,2	13,2±1,8	23,8±2,4
$\bar{\delta}^I(^1D_2)$	18,2	18,2	18,2	18,2	18,2

Table of phase shifts for sets 1,2,3,4 and 5.

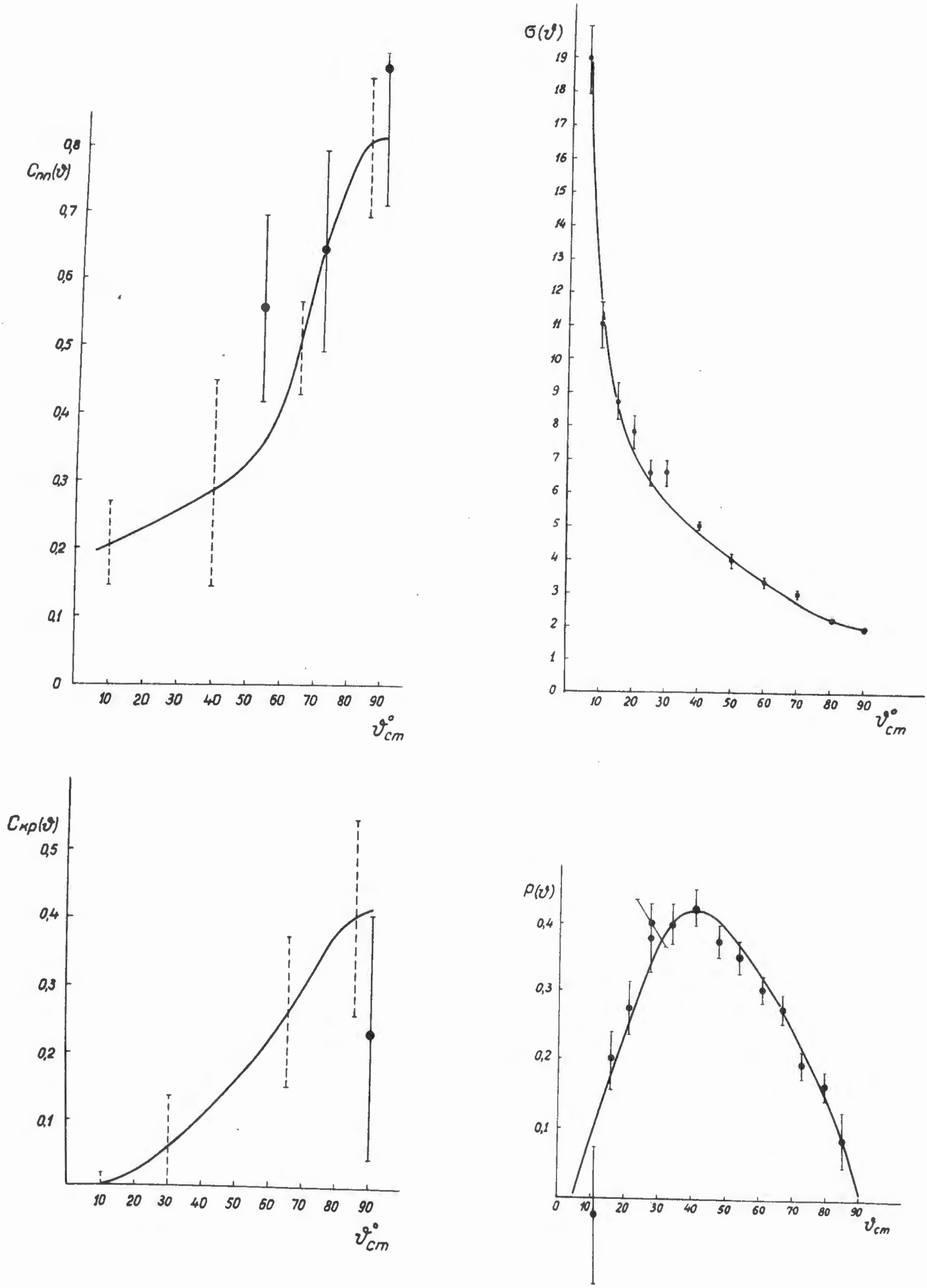

Fig. 1. Angular dependences $\sigma(\theta)$, $P(\theta)$, $C_{nn}(\theta)$, $C_{kp}(\theta)$ according to set I. -experimental points; -calculating corridor of errors.

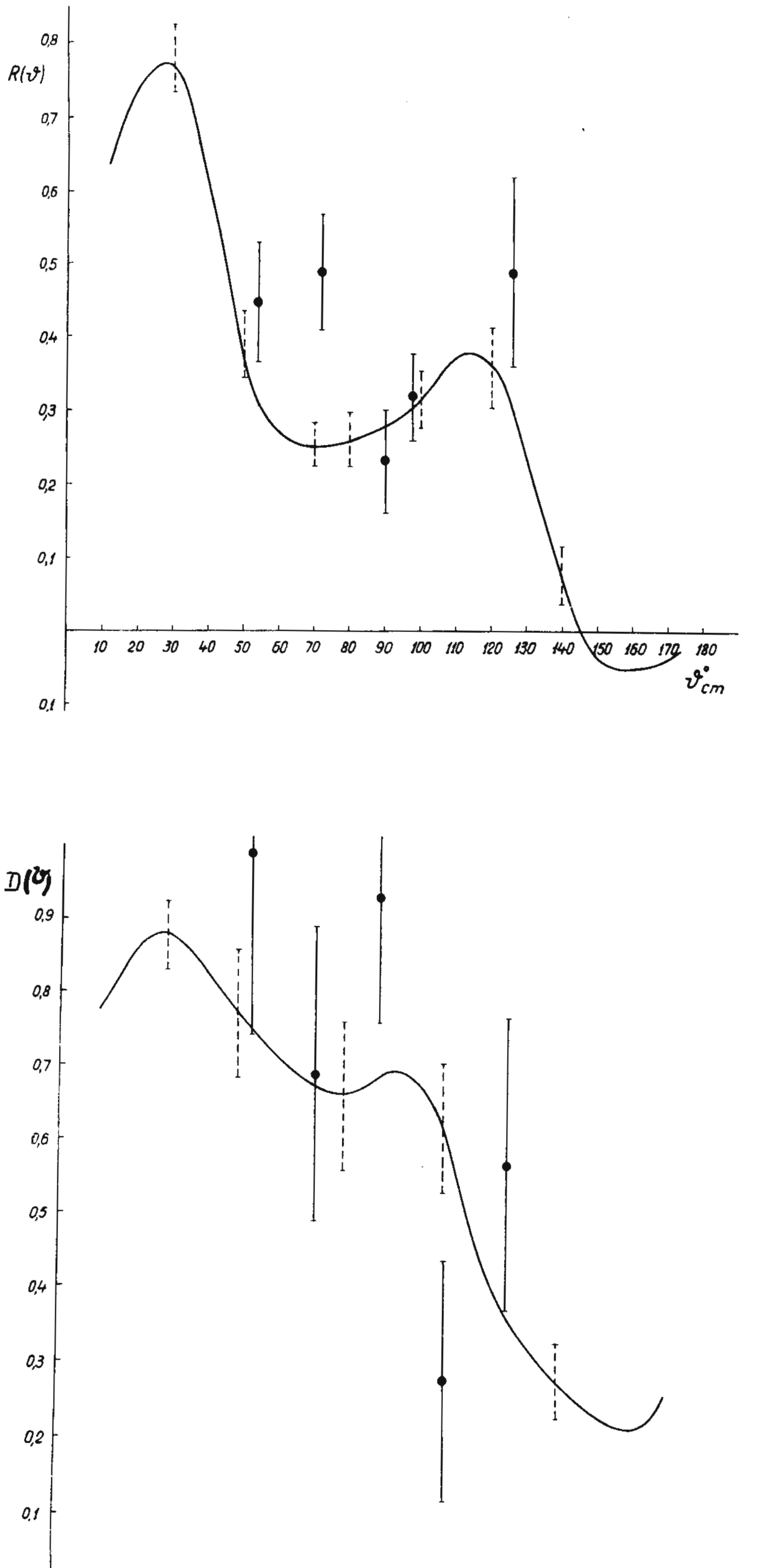

Fig. 2. Angular dependences of the parameters $D(\theta)$ and $R(\theta)$ according to phase shift set I. -experimental points; -calculation corridor of errors.

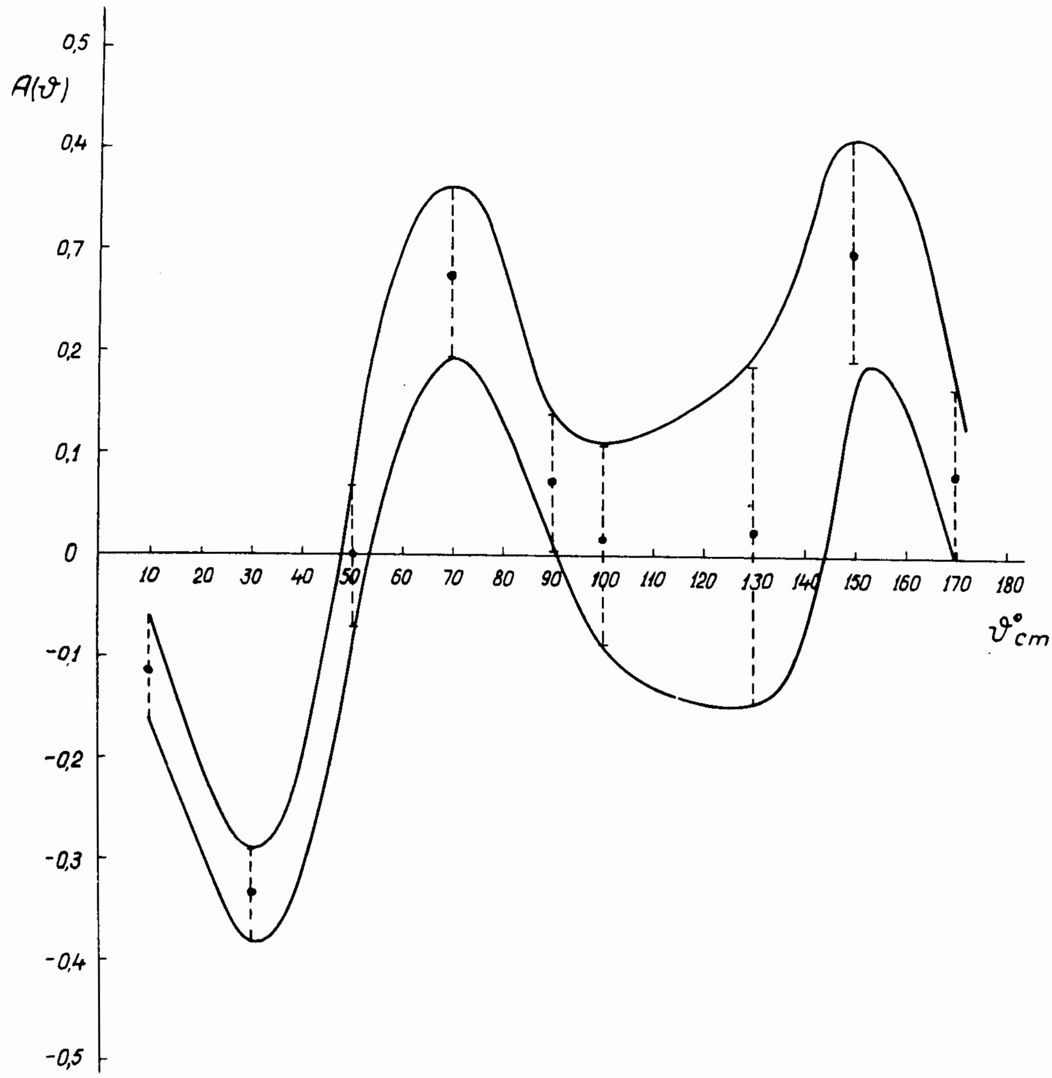

Fig. 3. Predicted values of the parameter A(θ) according to phase shift set I. -calculation corridor of errors.

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