ЯФ, 1966, т. 4, в. 4,
с. 892-895.

ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E-2609

ЛАБОРАТОРИЯ ЯДЕРНЫХ ПРОБЛЕМ

S.I.Bilenkaya, Z.Janout, Yu.M.Kazarinov, F.Lehar

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Submitted to Jad. Phys.

The phase-shift analysis of nucleon-nucleon scattering at 23.1 MeV[1] carried out using the experimental data given in refs.[2-7] gave three sets of phase shifts with approximately equal probabilities. The addition of new data on the triple scattering parameters R_{pp} and A_{pp} [8] (three points for each parameter) excluded the third set of phase shifts[9]. However, some of the parameters in the solutions were determined with errors larger than 100%. Owing to this, for example, even the sign of the mixing parameter ϵ_1 which characterizes the admixture of tensor forces in the low-energy np -interaction remains undetermined. The planning of experiments carried out by the method of Sokolov[10] has proved that it would be rather interesting to measure the spin correlation coefficient in np -scattering in order to decrease errors in the parameters, corresponding to isotopic spin T=0.

The use of a polarized proton target (PPT) in nucleon-nucleon scattering experiments in the low energy region made it possible to measure the spin correlation coefficients rather accurately[11,12]. In this connection the phase-shift sets at the mean energy 23.1 MeV obtained earlier[2-8] were specified using the new data from refs.[11,12] (Table 1).

$$C^{pp}_{nn}\ (25.7\ \text{MeV}, 90°) = -0.725 \pm 0.014 \quad [11]$$

$$A^{pp}_{ss}\ (25.7\ \text{MeV}, 90°) = -0.925 \pm 0.015 \quad [11]$$

$$C^{np}_{nn}\ (23.0\ \text{MeV}, 175°) = -0.01 + 0.01 \quad [12] \qquad (1)$$

The first set of phase shifts turned out to be in agreement with the χ^2-criterion ($\chi^2/\bar{\chi}^2 = 1.04$); the second and third ones can be rejected since $\chi^2/\bar{\chi}^2 > 2$ [x)].

The quantity A_{ss} used in the phase-shift analysis is an element of the asymmetry tensor A_{ij}, determined by the expression[14,15]

$$I_0 A_{ij} = \tfrac{1}{4}\, Sp\, M^+ M \cdot \sigma_{1i}\, \sigma_{2j} \qquad (2)$$

where I_0 is the differential cross section for the scattering of an unpolarized beam on an unpolarized target; M is the scattering amplitude and σ_{1i} (σ_{2j}) are the Pauli matrices. The tensor A_{ij} is connected with the tensor of spin correlation by the relation

x) The pronounced disagreement between the angular dependence of the spin correlation tensor components in the scattering of polarized neutrons on a PPT and the pure S-scattering predictions for these quantities, found earlier[13] also served as an argument against the third set.

$$A_{ij}(\vec{k}', \vec{k}) = C_{ij}(-\vec{k}, -\vec{k}') \qquad (3)$$

from time reversal invariance ($\vec{k}$, $\vec{k}'$ are the initial and final relative moments).

A_{ij} are asymmetry functions with a proton polarized in the i-direction incident on a target proton, polarized in the j-direction. The differential cross section in this case (in the lab. system) is given by the formula[14,17]:

$$I = I_0 \{ 1 + P^0(\vec{P}_1 \vec{n}) + P^0(\vec{P}_2 \vec{n}) + A_{nn}(\vec{P}_1 \vec{n})(\vec{P}_2 \vec{n}) +$$

$$+ A_{kk}(\vec{P}_1 \vec{k})(\vec{P}_2 \vec{k}) + A_{ks}[(\vec{P}_1 \vec{k})(\vec{P}_2 \vec{s}) + (\vec{P}_1 \vec{s})(\vec{P}_2 \vec{k})] +$$

$$+ A_{ss}(\vec{P}_1 \vec{s})(\vec{P}_2 \vec{s}) \} \qquad (4)$$

where P^0 is the polarization in the scattering of an unpolarized beam on an unpolarized target, P_1 the polarization of the nucleon beam, P_2 is the polarization of the PPT

$$\vec{n} = \frac{\vec{k} \times \vec{k}'}{|\vec{k} \times \vec{k}'|}, \qquad \vec{s} = \frac{\vec{n} \times \vec{k}}{|\vec{n} \times \vec{k}|}.$$

A_{ij} can be expressed in terms of the matrix elements of the scattering matrix in the singlet-triplet representation as:

$$I_0 A_{kk} = \tfrac{1}{2}(|M_{01}|^2 - |M_{10}|^2 + |M_{11}|^2 + |M_{1-1}|^2) - \tfrac{1}{4}(|M_{00}|^2 + |M_{ss}|^2)$$

$$I_0 A_{ss} = \tfrac{1}{4}(|M_{00}|^2 - |M_{ss}|^2) - \tfrac{1}{2}(|M_{01}|^2 - |M_{10}|^2) + \mathrm{Re}\, M^*_{11} M_{1-1}$$

$$I_0 A_{ks} = \tfrac{1}{4}\,\mathrm{tg}\,\theta\,(|M_{11}|^2 + |M_{1-1}|^2 - |M_{00}|^2 - 2\mathrm{Re}M^*_{11} M_{1-1}) - \tfrac{1}{2}\,\mathrm{cotg}\,\theta\,(|M_{01}|^2 - |M_{10}|^2)$$

$$I_0 A_{nn} = I_0 C_{nn} \qquad (5)$$

The inclusion of data on C_{nn} and A_{ss} into the phase-shift analysis made it possible to move the lower limit of the unique determination of the nucleon-nucleon scattering amplitude from 52 to 23.1 MeV. The obtained solution is stable and another number of variable parameters from 12 to 17 does not change the mean values of the phase shifts by more than one error (Table 1). The errors in the mixing parameters ϵ_1 and the phase shift $^3S_1$ were sharply decreased. Not only the sign of the parameter ϵ_1 is now well-determined but also its mean value. The obtained value $\epsilon_1 = -4.86 \pm 1.39$ indicates that the available experimental data are in contradiction with the value ϵ_1 given in refs.[18-21]. It is worth nothing that, as H.P.Noyes has reported[22], the phase-shift analysis at the energy near 25 MeV at which somewhat different data were treated provided a negative value for

$\epsilon_1 = -3.44 \pm 1.54$ [22]. If a coupling constant f^2 is considered to be a free parameter, its value for $\ell_{max} = 2$ differs significantly (by more than three errors) from the value found in πp-scattering ($f^2 = 0.08 \pm 0.02$)[23]. However, if f^2 is fixed and taken to be equal to 0.08, the solution, as can be seen from Table 1, does not change for other parameters. This may indicate that for $\ell_{max} = 2$ the singularities of the amplitude lying beyond the one-meson pole give a noticeable contribution to the part of the amplitude taken in the one-meson approximation. Unfortunately, the increase of $\ell_{max} = 3$ considerably increases the error in the determination of f^2 and its value does not contradict to the value 0.08 within the experimental error.

The phase-shifts given in Table 2 were used to calculate the experimental quantities the diagrams of which are presented in Figs. 1-10. The vertical lines on the figures show the corridor of errors for the calculated curves.

In conclusion the authors express their deep gratitude to L.I.Lapidus and P.Winternitz for useful discussions, to H.P.Noyes for private communication and to L.F.Gratcheva, J.Fingrova and A.M.Fokina for help in the work.

References

1. Ю.М. Казаринов, В.С. Киселев, В.И. Сатаров. Препринт ОИЯИ Р-1553, Дубна 1964.
2. E.R.Flynn, P.J.Bendt. Phys. Rev., 128, 1268 (1962).
3. T.H.Jeong, L.J.Johnston, D.E.Young, C.N.Wadwell. Phys. Rev., 118, 1080 (1960).
4. P.Christmas, A.E.Taylor. Nucl. Phys., 41, 388 (1963).
5. J.P.Scanlon, G.H.Stafford, J.J.Thresher, P.H.Bowen, A.Langsford. Nucl. Phys., 41, 401 (1963).
6. R.B.Perkins, J.E.Simmons. Phys. Rev., 130, 272 (1963).
7. A.Abragam, M.Borghini et al. Phys. Pett., 2, 310 (1962).
8. A.Ashmore et al. Nucl. Phys. , 73, 256 (1965).
9. Ю.М. Казаринов, В.С. Киселев, Ю.Н. Симонов. Препринт ОИЯИ Р-2241, Дубна 1965.
10. С.Н. Соколов. Препринт ОИЯИ, Д-573, Дубна 1960.
11. P.Catillon, M.Chapellier, D.Garreta, J.Thirion. Karlsruhe Conference paper 8-4, (1965).
12. P.Bendt, J.J.Malanify, T.R.Roberts, J.E.Simmons. Karlsruhe Conference paper 5/8-3 (1965).
13. П. Винтерницц, Ф. Легар, З. Яноут. Препринт ОИЯИ Р-2407, Дубна 1965.
14. С.М. Биленький, Л.И. Лапидус, Р.М. Рындин. УФН, 84, 243 (1964).
15. A.E.Woodruff. Ann. of Phys., 7, no. 1, 65 (1959).
16. В.В. Владимирский, Я.А. Смородинский. ДАН СССР, 104, 713 (1955).
17. С.М. Биленький, Л.И. Лапидус, ЛР.М. Рындин. ЖЭТФ, 49, 1653 (1965); Препринт ОИЯИ Р-2227, Дубна 1965.
18. G.Breit, M.H.Hull, K.E.Lassila, H.M.Pyatt, H.M.Ruppel. Phys. Rev., 128, 826 (1962).
19. M.H.Hull, K.E.Lassila, H.M.Ruppel, F.A.McDonald, G.Breit. Phys. Rev., 128, 830 (1962).
20. Г. Брейт. Труды ХП -ой международной конференции по физике высоких энергий, Дубна 1964.
21. T.Hamada, J.D. Johnston. Nucl. Phys., 34, 382 (1962).
22. H.P.Noyes. private communication.
23. W.S.Woolcook. Proc. 1960. Ann. Intern. Conf. on H.E.Phys., p.302.
24. H.P.Stapp, J.Y.Ypsilantis, N.Metropolis, Phys. Rev., 105, 302 (1957).
25. R.B.Perkins, J.E.Simmons. Congres International de physique nucleaire, vol.II, Paris 1964, p.164.

Received by Publishing Department
on March 5, 1966.

Table 1

Effective energy in MeV	Measured quantity	Number of points	Actual experimental energy in MeV	Ref.
23,1	σ^{pp}	23	25,63 corr.	3
	P^{pp}	1	27,4	4
	σ^{np}	11	22,5 - 27,5 interp	5
	σ^{np}	12	22,5 corr.	2
	P^{np}	6	23,1	6
	C^{pp}_{nn}	1	20	7
	C^{pp}_{nn}	1	25,7	11
	R^{pp}	3	25,7	8
	D^{np}	3	23	25
	A^{pp}	3	25,7	8
	A^{pp}_{ss}	1	25,7	11
	C^{np}_{nn}	1	23	12

Designations: interp ... interpolated values of the cross sections were used.

cor. ... corrected according to the ratio of the cross-sections at 90^{o} using data at T=25,63 and 21,9 MeV for σ^{pp} and according to the total cross-section for σ^{np}.

Table 2

The phase-shifts in degrees (the Stapp[24] parametrization) for 23.1 MeV nucleon-nucleon scattering

	$l_{max} = 2$		$l_{max} = 3$	
f^2	$0.08_{fix.}$	0.171±0.027	$0.08_{fix.}$	0.315±0.173
$^1S_0$	50.01±0.20	50.62±0.22	50.54±0.26	50.39±0.27
$^3S_1$	97.49±4.09	99.41±3.72	96.41±4.74	98.87±3.91
$^3P_0$	9.19±0.35	7.70±0.55	7.81±0.71	8.48±0.77
$^1P_1$	0.69±1.05	1.82±0.86	-0.19±1.36	0.77±1.36
$^3P_1$	-5.13±0.17	-4.25±0.34	-4.69±0.43	-4.68±0.39
$^3P_2$	2.78±0.09	2.62±0.09	2.38±0.37	2.63±0.36
ϵ_1	-4.86±1.39	-3.70±1.22	-4.38±1.22	-2.89±1.83
$^3D_1$	-2.97±1.29	-4.37±1.40	-3.04±1.93	-4.46±2.08
$^1D_2$	0.81±0.03	1.12±0.08	1.08±0.07	1.12±0.08
$^3D_2$	3.42±4.03	4.78±3.41	2.56±5.14	3.63±4.04
$^3D_3$	-0.03±1.16	-0.45±0.94	-0.47±1.04	-1.01±0.73
ϵ_2			-1.18±0.25	-1.12±0.22
$^3F_2$			-0.20±0.33	-0.37±0.34
$^1F_3$			0.26±0.65	-0.36±0.76
$^3F_3$			0.43± 0.63	0.42±0.60
$^3F_4$			-0.14±0.17	-0.26±0.17
χ^2	67.4	56.13	54.47	53.22

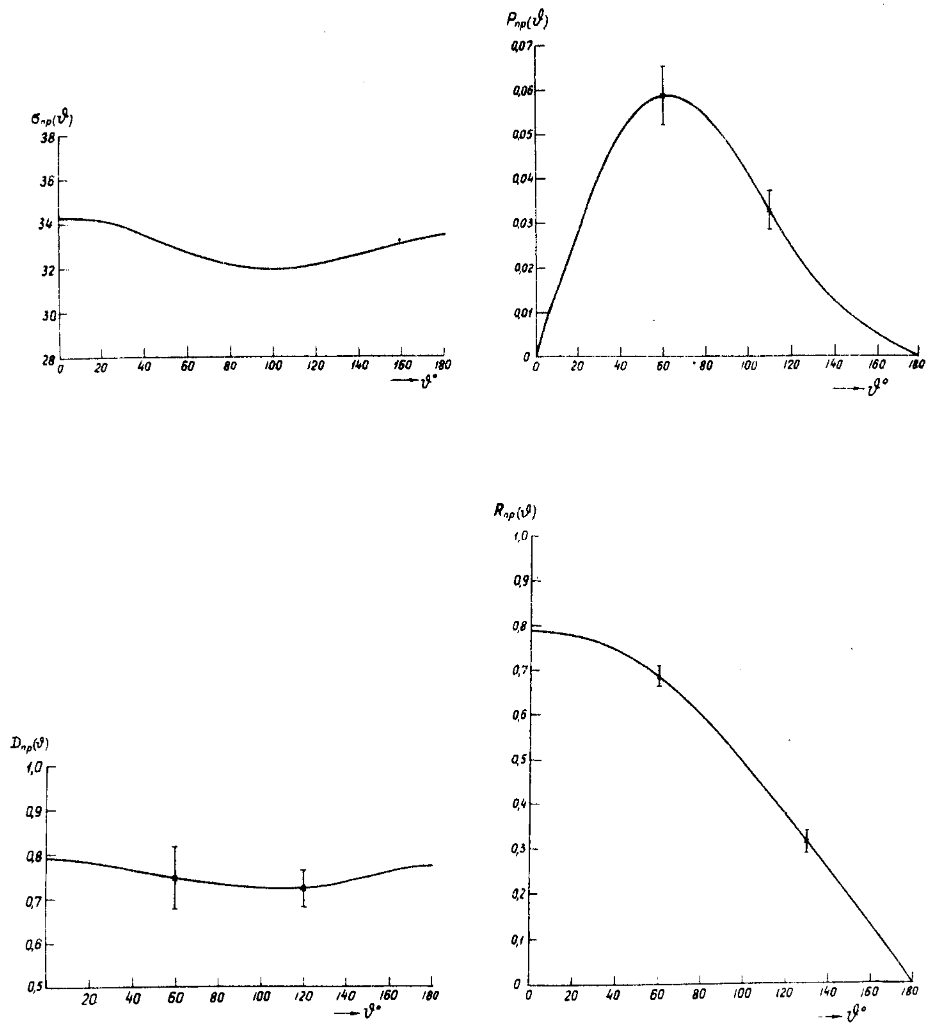
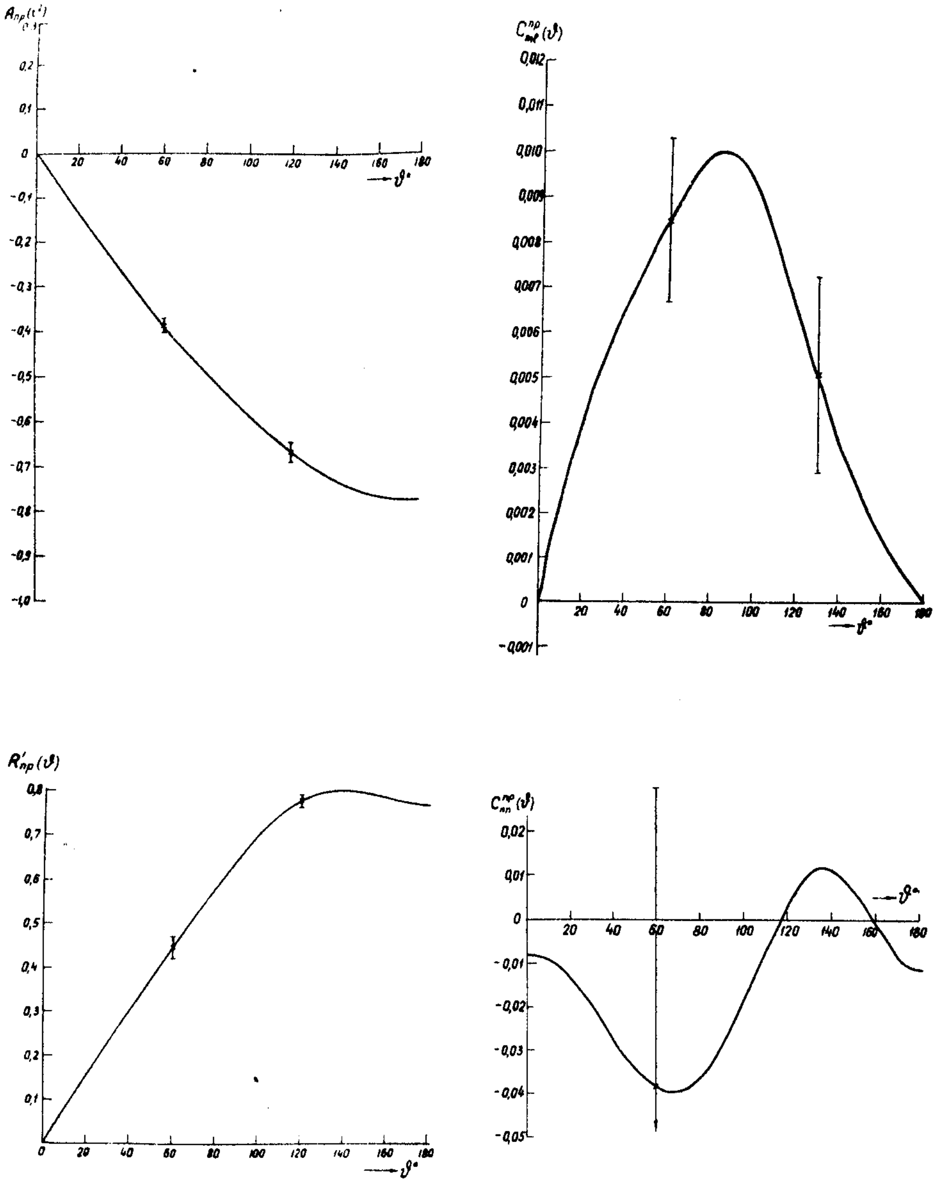
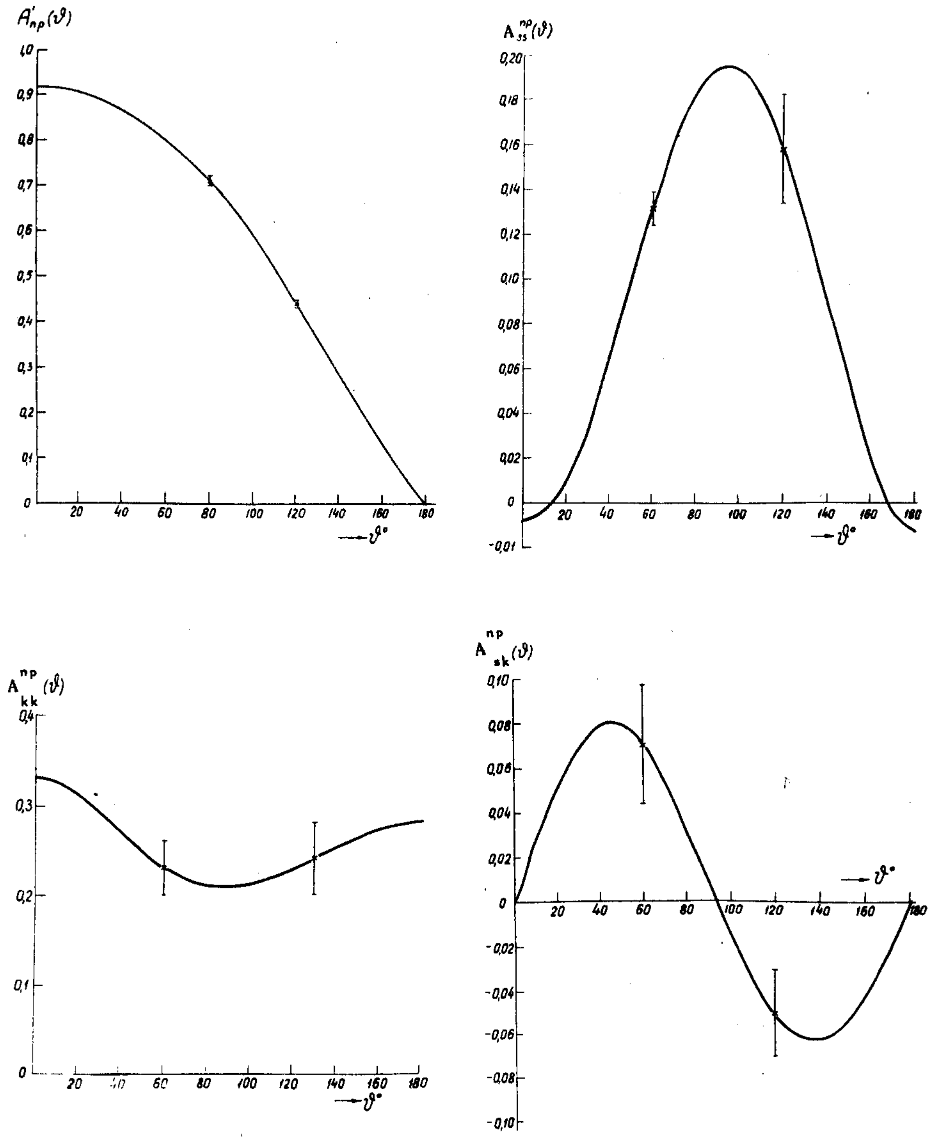


Fig.1.



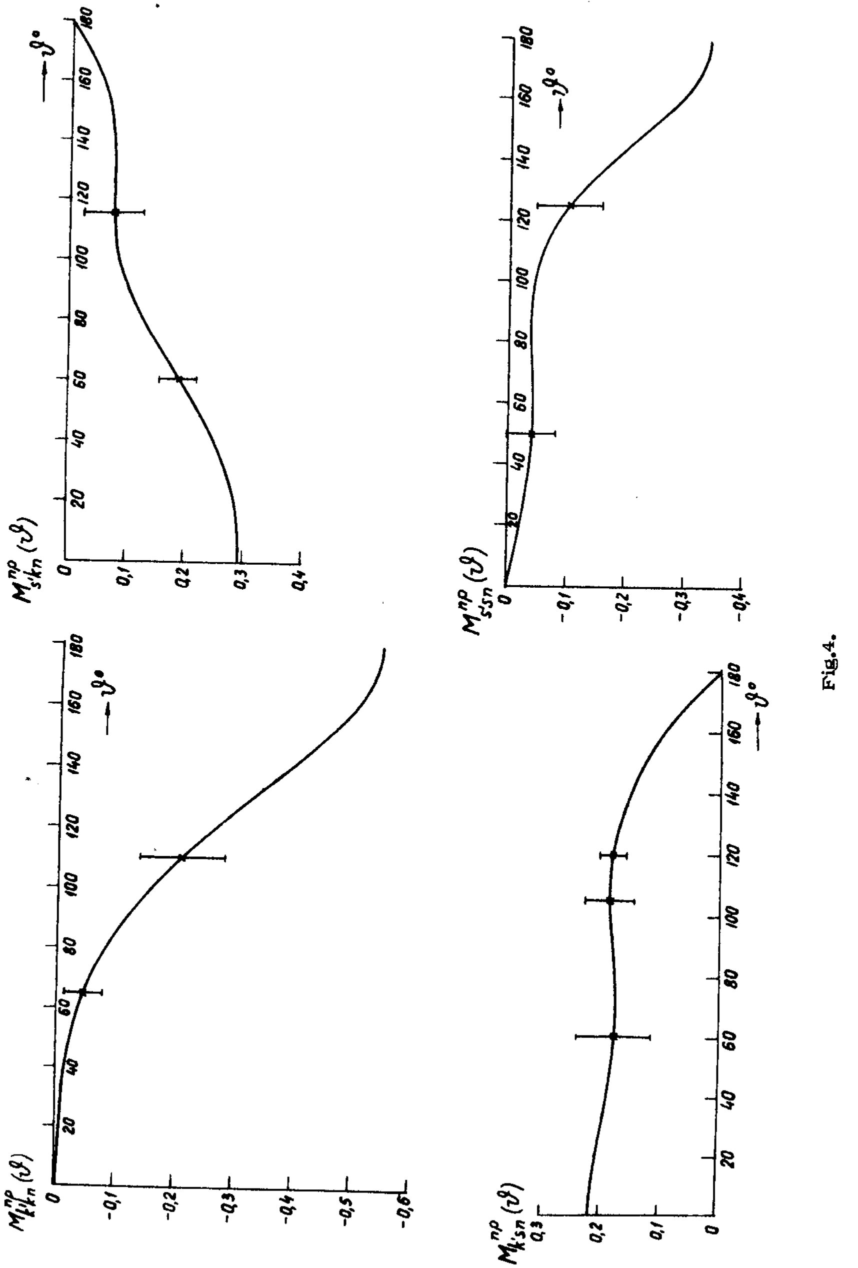
$C^{np}_{nn}(\vartheta)$
$R'_{np}(\vartheta)$
$\vartheta°$

Fig.2.



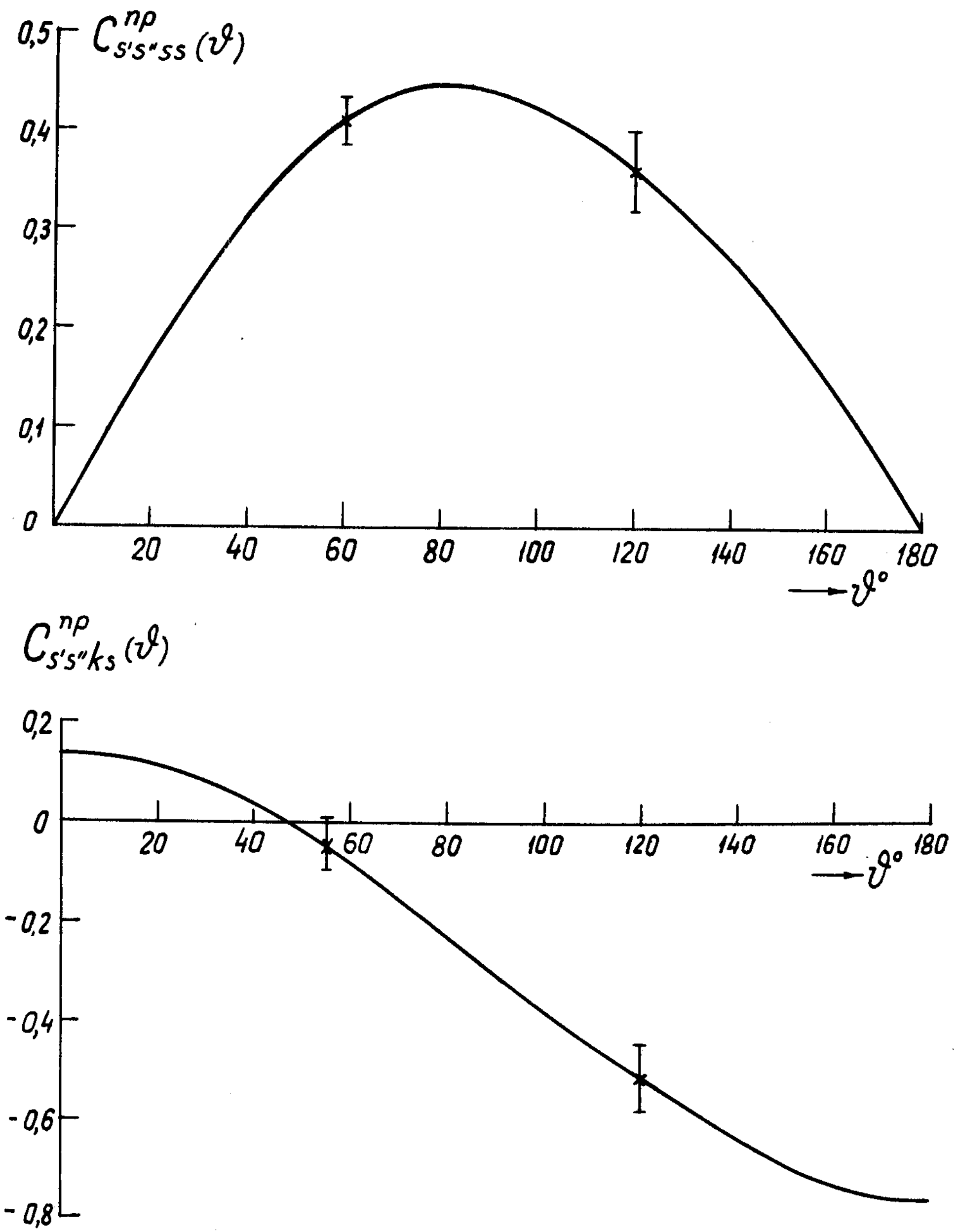
$A'_{np}(\vartheta)$
$A^{np}_{ss}(\vartheta)$
$A^{np}_{kk}(\vartheta)$
$A^{np}_{sk}(\vartheta)$
$\vartheta°$

Fig.3.



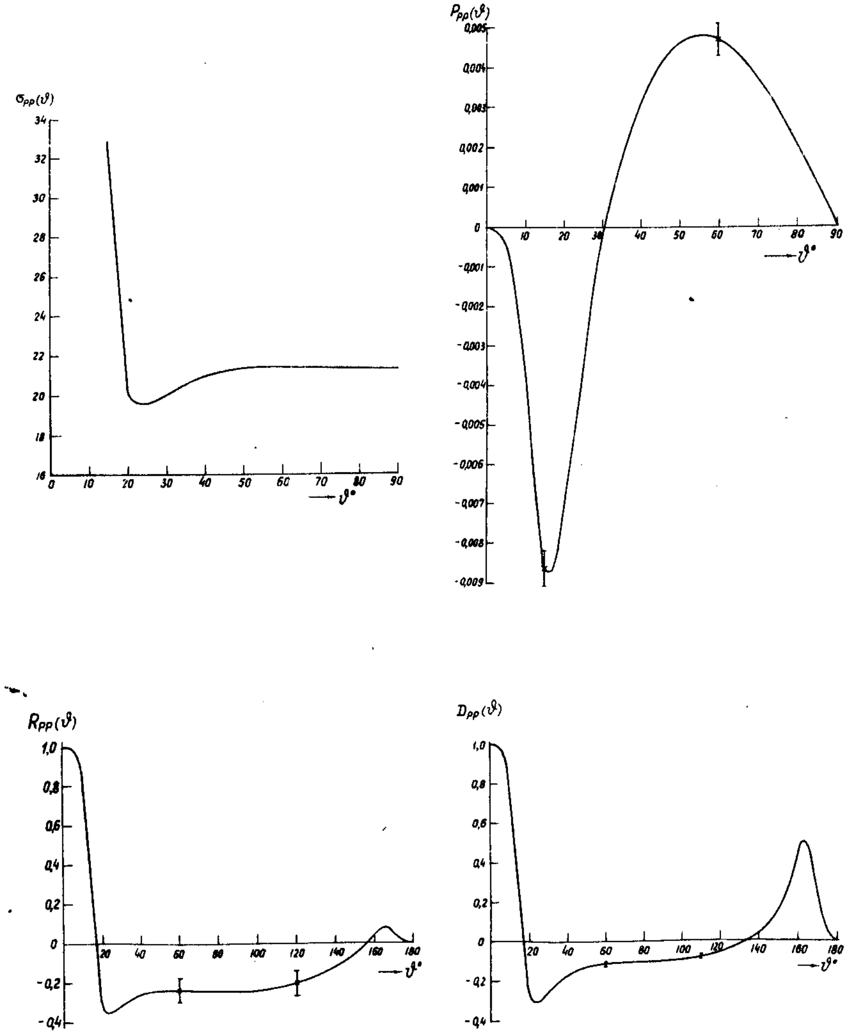
$M^{np}_{s'k'n}(\vartheta)$
$M^{np}_{s's'n}(\vartheta)$
$M^{np}_{k'k'n}(\vartheta)$
$M^{np}_{k's'n}(\vartheta)$
ϑ°

Fig.4.



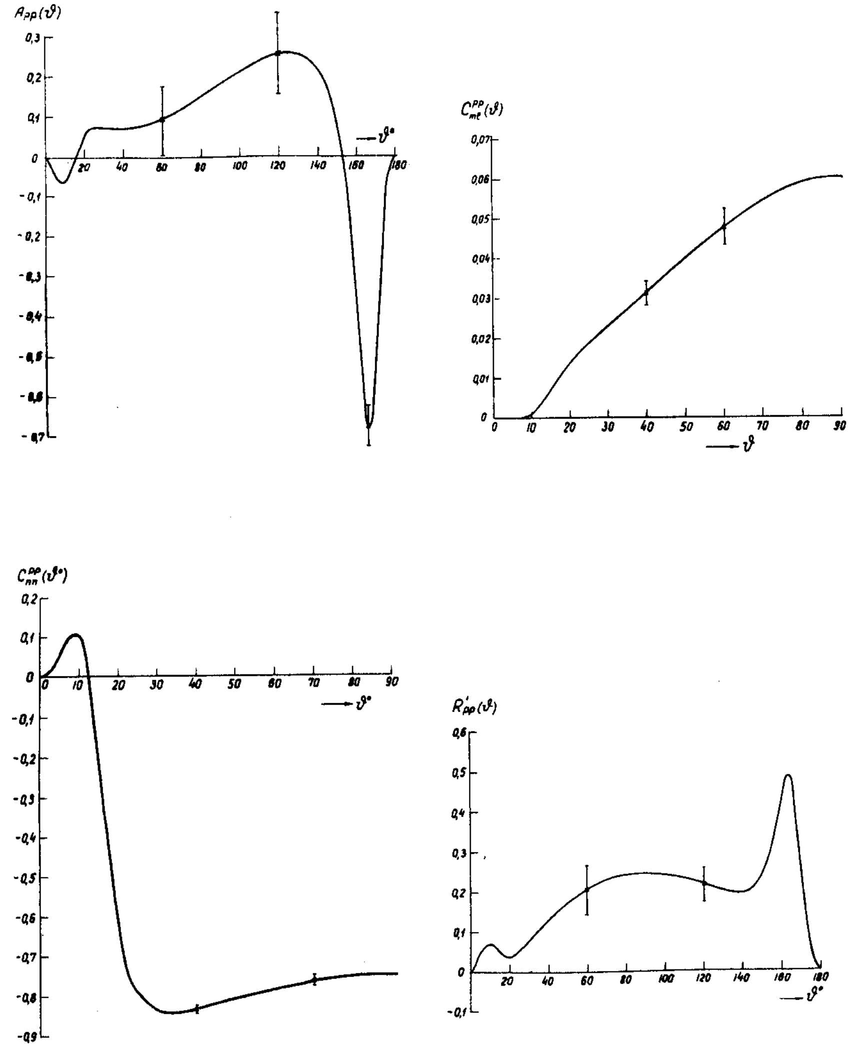
$C^{np}_{s's''ss}(\vartheta)$
0,5
0,4
0,3
0,2
0,1
0
20
40
60
80
100
120
140
160
180
ϑ°
$C^{np}_{s's''ks}(\vartheta)$
0,2
0
-0,2
-0,4
-0,6
-0,8

Fig.5.



$\sigma_{pp}(\vartheta)$
$P_{pp}(\vartheta)$
$R_{pp}(\vartheta)$
$D_{pp}(\vartheta)$
$\vartheta°$

Fig.6.



$A_{pp}(\vartheta)$
$C_{mt}^{pp}(\vartheta)$
$C_{nn}^{pp}(\vartheta°)$
$R'_{pp}(\vartheta)$
$\vartheta°$

Fig.7.

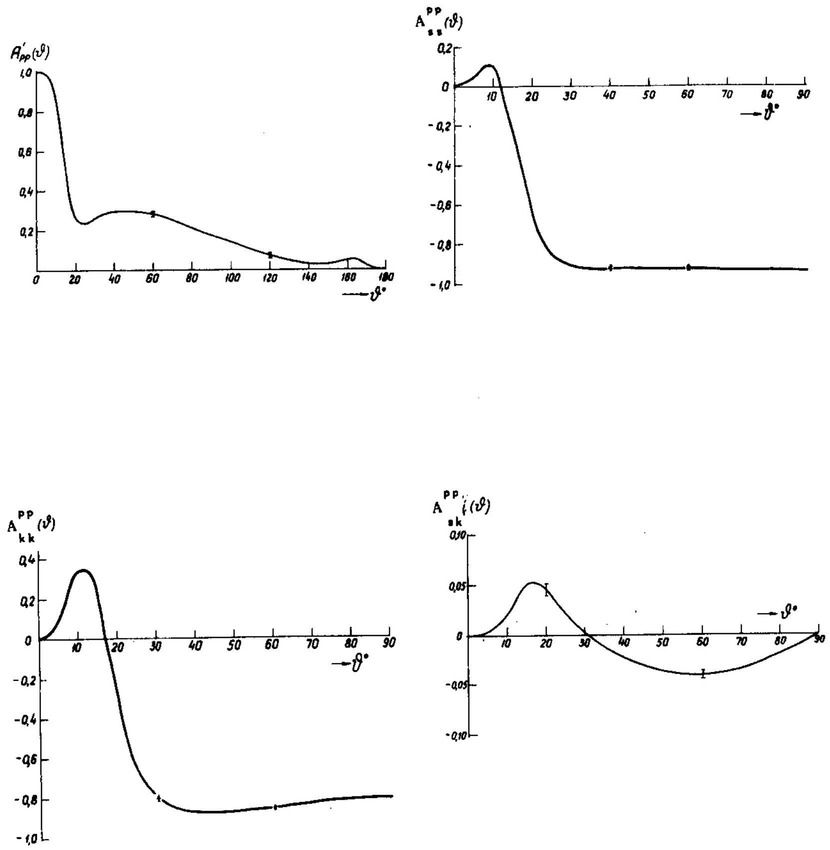


Fig.8.

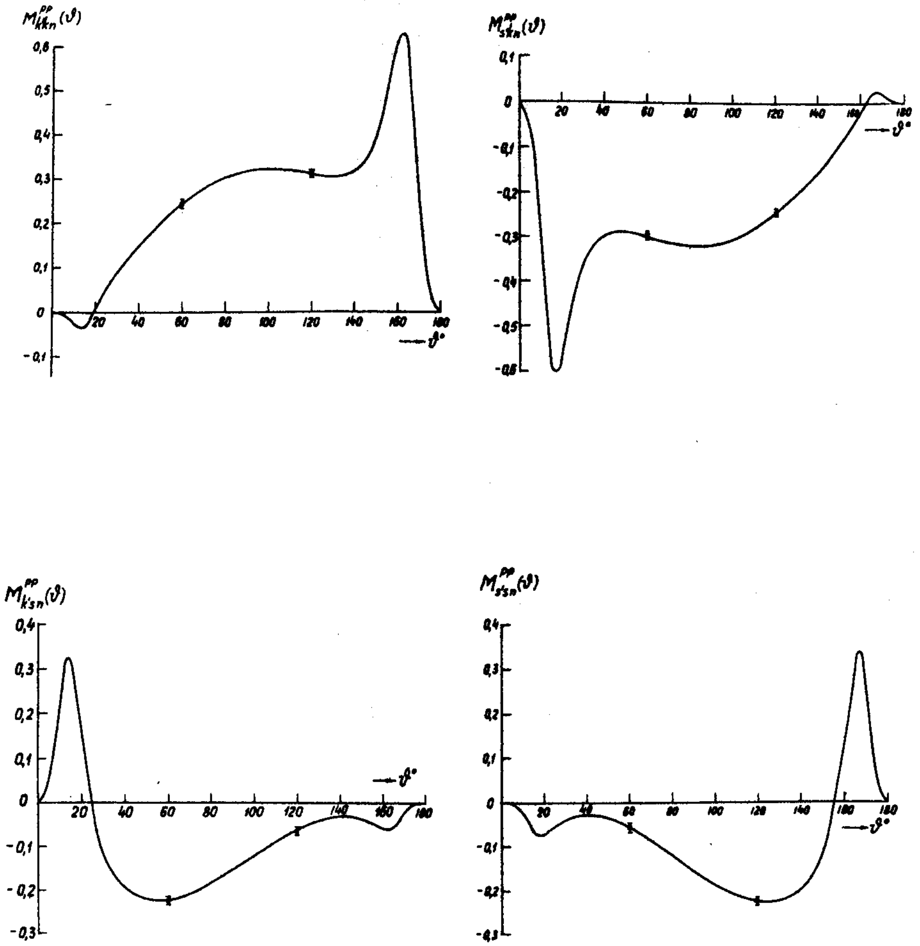
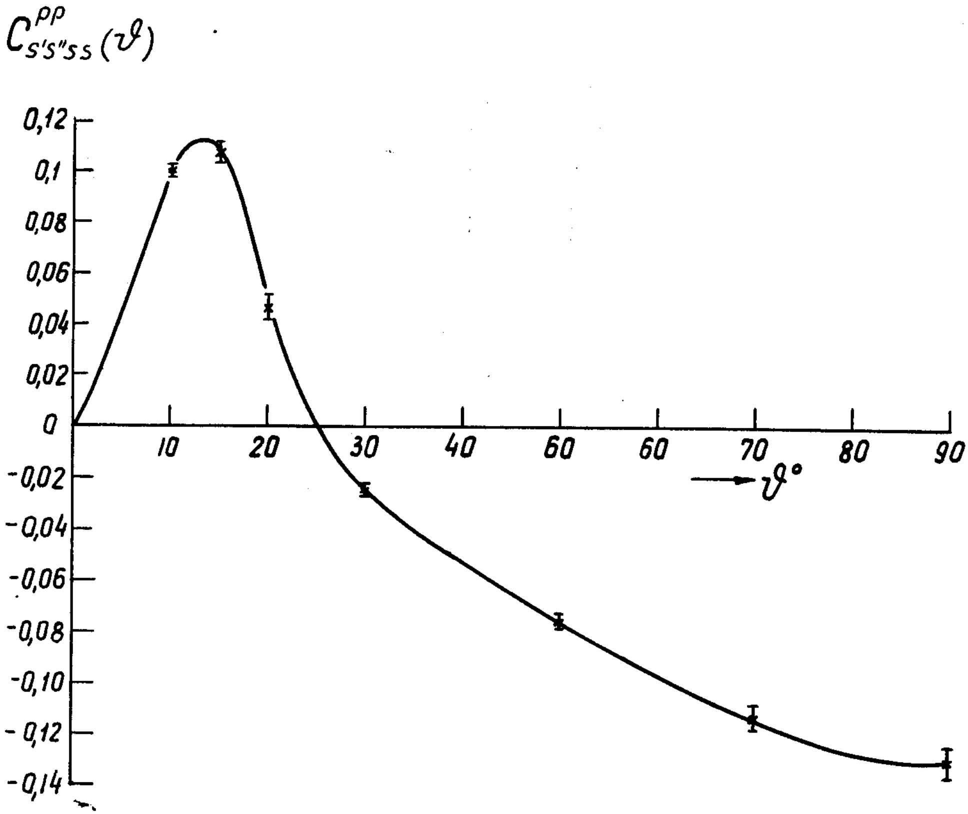
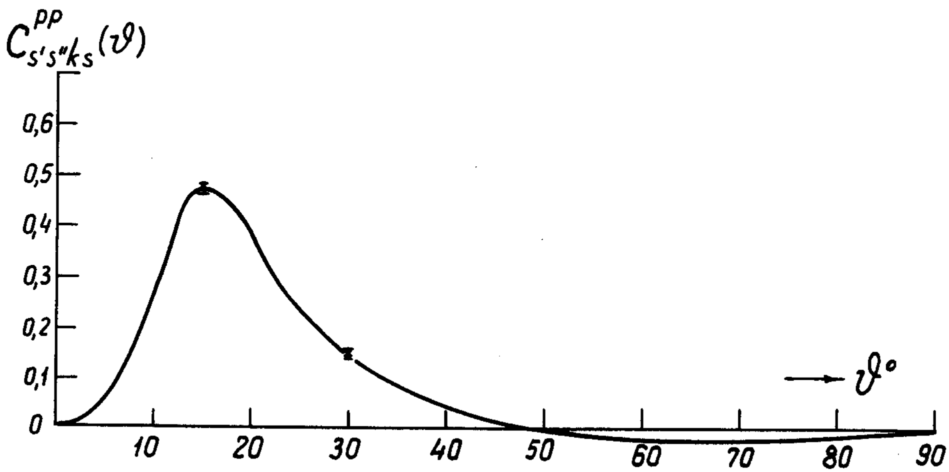


Fig.9.



$C^{pp}_{s's''ss}(\vartheta)$
0,12
0,1
0,08
0,06
0,04
0,02
0
-0,02
-0,04
-0,06
-0,08
-0,10
-0,12
-0,14
10
20
30
40
60
60
70
80
90
$\vartheta°$



$C^{pp}_{s's''ks}(\vartheta)$
0,6
0,5
0,4
0,3
0,2
0,1
0
10
20
30
40
50
60
70
80
90
$\vartheta°$

Fig. 10.