ОБЪЕДИНЕННЫЙ
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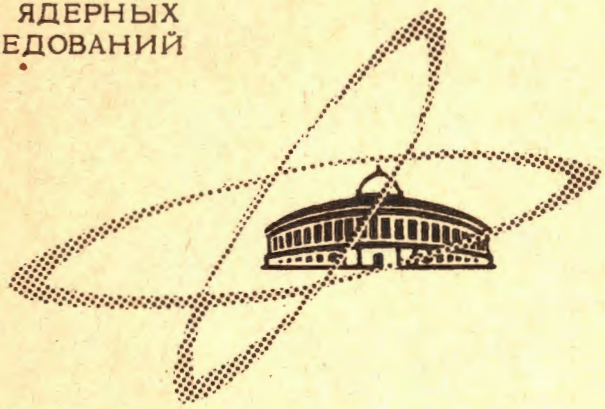

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SPECIFICATION OF THE N-N PHASE SHIFT ANALYSIS AT 147 MEV

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Several papers containing data on the differential cross-section and polarization in pp and np scattering have been published, as a result of the extensive investigation of the nucleon interaction at 140 - 150 MeV. However, it was shown, that there are systematical errors in many of the measurements, mainly due to the inaccurate determination of the primary beam characteristics[1]. Besides, the present accuracy of the differential cross section makes an account of the differences between the primary beam energies in various experiments desirable. For these reasons in the present paper we specify the phase shift analysis previously carried out in Dubna[2] at 147 MeV. The data from all existing experiments at energies near to 147 MeV were renormalized by a method described below before they were included in the phase-shift analysis. The experimental data used for the specification of the phase-shift analysis are presented in Table 1. The coefficients by which the experimental data should be divided in order to normalise them to the energy 147 MeV are given in the same table. The coefficients were obtained as follows: the angular dependence of the given experimental quantity was approximated by the analytical function $N_j f(a_k \theta_i)$. N_j is the normalization coefficient and the function $f(a_k \theta_i)$ was taken in the form used in ref[3]. The parameters a_k and coefficients N_j were determined by the least square method together with their errors.

The differential cross sections were renormalized by finding the minimum of the functional

$$\chi^2 = \sum_{ij} \frac{[\sigma^j(\theta_i) - N_j f(a_k \theta_i)]^2}{\Delta_{ij}^2} + \frac{[\sigma_{tot} - \int_\Omega f(a_k \theta) d\Omega]^2}{\Delta_{tot}^2}, \qquad (1)$$

were Δ_{tot}, Δ_{ij} are the experimental errors, θ is the scattering angle in the c.m.s.

The lower limit of the integral for the determinations of the total pp - scattering cross section was taken as 12°, since the experimental value of σ_{tot}^{pp} was

obtained in the same range of scattering angles. The experimental values $\kappa\sigma^{j}(\theta_i)$ correspond to the i-th point in j-th group of experiments.

The renormalization coefficients for the polarization in pp-scattering were determined by minimalizing the functional

$$\chi^2 = \sum_{ij} \frac{[P^j(\theta_i) - N_j f(a_k \theta_i)]^2}{\Delta^2_{ij}} . \qquad (2)$$

In this formula $f(a_k \theta_i) = a_0 + \sin\theta_i \sum_k a_k \cos^k \theta_i$.
The renormalization coefficient N_j, corresponding to data, obtained at the energy 147 MeV was set egual to 1/0.933 and fixed[1].

Unfortunately, no the np-scattering data exist at 147 MeV. Therefore, the $P_{np}(\theta)$ data at 140 and 143 MeV[x], multiplied by the correction factors from ref.[1] were used. Both renormalization factors were varied by minimalizing the functional (2). It is interesting to note, that the ratio of the correction coefficient from ref.[1] and the corresponding values N_j are equal to unity within the errors. All other experimental values, were used without corrections for the difference in the energies.

The phase-shift analysis was carried aut according to the program presented in ref.[29]. Beginning from the orbital momenta $\ell_{max} = 4 - 6$, the scattering amplitude was taken in the one pion exchange approximation. The phase-shifts obtained as the result of the specification are given in Table 2. The previously obtained solution at 147 MeV is given for comparison. It follows the Table 2, that the errors of the phase shifts are considerably decreased. The $^1P_1$, $^3D_3$, ϵ_1, $^3G_4$, $^3G_5$ phase shifts changed more than within 2-3 errors. It should be noted that the new phase-shifts are in better agreement with the values obtained by the interpolation of the corresponding phase-shifts at the neighbouring energies than the old ones.

The angular dependences of the experimental guantities were calculated using the obtained phase shifts and are presented on Figs. 1-10. The vertical lines show calculated corridor of errors.

In conclusion the authors ish to express their deep gratitude to B.Rose and D.F.Measday for sending their information on the normalization factors prior to publication. The authors also thank to E.Dudova, J.Fingerova and A.M.Fokina for help in the work.

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x/ The polarization P_{np} in the energy region 140-150 MeV varies slowly with the energy[1].

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Table 1

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
σ_{pp}	144.1	16.6	3.574	0.029	1.047±0.029	[4]
		18.7	3.703	0.032		
		20.7	3.779	0.026		
		25.9	3.940	0.023		
		31.1	4.041	0.024		
		36.2	4.018	0.018		
		41.4	4.014	0.013	1.039±0.028	
		46.5	4.019	0.014		
		51.6	3.977	0.012		
		56.8	3.944	0.011		
		61.9	3.914	0.011		
		66.9	3.907	0.015		
		72.0	3.880	0.014		
		77.1	3.875	0.015		
		82.1	3.813	0.014		
		87.1	3.819	0.016		
		92.1	3.833	0.015		
		97.1	3.837	0.016		
		102.1	3.838	0.017		
		107.0	3.850	0.018		
		112.0	3.859	0.017		
	147	12.4	3.79	0.10	1.141±0.029	[5]
		14.5	3.88	0.10		

Quantity	E nergy MeV	Angle in deg. c.m.s.	Experi-mental value	Error	Norm	Ref.
σ_{pp}	147	16.6	4.02	0.10	1.141±0.029	[5]
		18.7	4.03	0.10		
		20.7	4.15	0.10		
		22.8	4.14	0.11		
		24.9	4.26	0.11		
		31.1	4.22	0.11		
		20.7	4.17	0.08	1.105±0.028	
		25.9	4.29	0.08		
		31.1	4.39	0.08		
		36.3	4.31	0.08		
		41.4	4.21	0.04		
		46.5	4.21	0.04		
		51.7	4.16	0.04		
		56.8	4.14	0.04		
		61.9	4.12	0.04		
		67.0	4.12	0.04		
		72.0	4.07	0.04		
		77.1	4.06	0.05		
		82.1	4.07	0.05		
		87.2	4.11	0.05		
		92.2	4.12	0.05		
		97.1	4.13	0.05		
		102.1	4.12	0.05		
		107.1	4.14	0.05		
		112.0	4.09	0.05		
σ_{pp}	142	7.27	12.96	0.43	1.00 fix.	[6]

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
σ_{pp}	142	8.30	7.75	0.28	1.00 fix.	[6]
		8.82	5.76	0.30		
		9.34	4.91	0.25		
		10.38	4.37	0.21		
		10.38	4.32	0.14		
		12.46	3.63	0.13	1.065±0.033	
		14.53	3.77	0.14		
		20.76	3.74	0.13		
		25.95	3.83	0.16		
		10.38	4.27	0.04		
		12.46	3.34	0.06	0.973±0.027	
		14.53	3.28	0.05		
		16.61	3.39	0.05		
		20.76	3.63	0.05		
		25.95	3.62	0.06		
		31.06	3.62	0.06		
		41.34	3.66	0.05		
		25.95	3.77	0.07	1.038±0.029	
		31.06	3.90	0.07		
		41.34	3.89	0.07		
		51.62	3.96	0.07		
		61.84	3.90	0.07		
		71.98	4.00	0.07		
		82.06	4.02	0.07		
	156	8.05	8.48	0.25	0.994±0.027	[7]

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
σ_{pp}	156	12.1	3.37	0.09	0.994±0.027	[7]
		14.1	3.30	0.13		
		16.1	3.35	0.13		
		18.1	3.49	0.14		
		20.1	3.66	0.14		
		25.0	3.58	0.06		
		26.0	3.62	0.06		
		27.0	3.84	0.06		
		29.0	3.75	0.06		
		31.0	3.87	0.05		
		35.1	3.85	0.05		
		37.0	3.74	0.09		
		41.1	3.88	0.05		
		46.1	3.83	0.05		
		51.1	3.82	0.05		
		62.0	3.70	0.04		
		72.0	3.71	0.04		
		82.0	3.67	0.004		
		90.0	3.71	0.006		
		102.0	3.75	0.006		
		112.0	3.76	0.006		
σ_{tot}^{pp}	147	12.0	23.69	0.15		[8]

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
P_{pp}	147	3.34	0.045	0.014	1.072±fix.	[5]
		10.4	0.103	0.014		
		12.4	0.126	0.011		
		14.5	0.155	0.014		
		16.6	0.180	0.010		
		18.7	0.193	0.015		
		20.7	0.198	0.009		
		22.8	0.183	0.015		
		24.9	0.227	0.014		
		25.9	0.203	0.011		
		31.1	0.228	0.009		
		36.3	0.247	0.011		
		41.4	0.239	0.006		
		46.5	0.233	0.006		
		51.7	0.229	0.006		
		56.8	0.205	0.006		
		61.9	0.171	0.006		
		67.0	0.154	0.006		
		72.0	0.131	0.006		
		77.1	0.098	0.006		
		82.1	0.052	0.008		
		87.2	0.030	0.008		
		92.2	−0.006	0.009		
		97.1	−0.041	0.007		
		102.1	−0.068	0.008		
		107.1	−0.109	0.008		

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
P_{pp}	142	5.19	-0.037	0.034	1.086±0.037	[9]
		8.30	0.031	0.024		
		9.34	0.089	0.023		
		10.38	0.153	0.035		
		10.38	0.107	0.021		
		12.46	0.130	0.033		
		14.53	0.180	0.031		
		16.61	0.155	0.028		
		20.76	0.181	0.029		
		24.80	0.216	0.037		
		31.06	0.238	0.028		
		37.20	0.283	0.030		
		41.34	0.250	0.029		
		51.60	0.222	0.011		
		20.76	0.190	0.009	1.080±0.022	
		25.95	0.225	0.011		
		31.06	0.242	0.010		
		41 34	0.237	0.011		
		61.80	0.196	0.011		
		72.00	0.113	0.011		
		82.00	0.066	0.011		
		90.00	0.010	0.011		
		45.45	0.242	0.005	1.102±0.009	
		49.55	0.240	0.004		
		51.60	0.232	0.007		

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
P_{pp}	142	53.65	0.213	0.004	1.103±0.009	[9]
		57.70	0.205	0.006		
		59.75	0.197	0.005		
		61.80	0.180	0.005		
		65.90	0.170	0.005		
		69.95	0.141	0.005		
	137	31.1	0.195	0.005	0.922±0.018	[5]
		46.4	0.212	0.007		
		66.9	0.133	0.008		
	138	20.7	0.208	0.008	1.085±0.007	[10]
		24.84	0.224	0.005		
		28.97	0.227	0.005		
		33.09	0.247	0.005		
		37.21	0.245	0.006		
		41.32	0.245	0.006		
		45.43	0.234	0.005		
		49.53	0.222	0.005		
		53.62	0.219	0.005		
		57.70	0.193	0.006		
		61.78	0.189	0.006		
		65.84	0.147	0.007		
		69.90	0.142	0.005		
		82.01	0.070	0.005		

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
	140.7	16.6	0.1657	0.0091	0.942±0.005	[4]
		18.7	0.1672	0.0089		
		20.7	0.1767	0.0070		
		25.9	0.1896	0.0044		
		31.1	0.2114	0.0049		
		36.2	0.2057	0.0047		
		41.4	0.2089	0.0025		
		46.5	0.2006	0.0032		
		51.6	0.1981	0.0028		
		56.8	0.1828	0.0030		
		61.9	0.1564	0.0032		
		66.9	0.1316	0.0032		

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
P_{pp}	140.7	72.0	0.1068	0.0032	0.942±0.005	[4]
		77.1	0.0814	0.0030		
		82.1	0.0532	0.0034		
		87.1	0.0157	0.0034		
		92.1	−0.0144	0.0034		
		97.1	−0.0466	0.0036		
		102.1	−0.0718	0.0034		
		107.0	−0.0977	0.0034		
σ_{np}	137	6.3	8.9	1.0	0.988±0.058	[11]
		10.6	8.0	0.6		
		20.7	6.9	0.4		
		31.0	5.85	0.35		
		41.3	4.38	0.40		
		51.6	2.86	0 .40		
		61.8	2.70	0.40		
	133	20 - 30	6.55	0.75	1.042±0.037	[12]
		30 - 40	5.59	0.59		
		40 - 50	3.86	0.44		
		50 - 60	3.31	0.38		
		60 - 70	2.45	0.31		
		70 - 80	2.96	0.33		
		80 - 90	2.64	0.31		
		90 - 100	2.54	0.30		
		100 - 110	3.13	0.34		
		110 - 120	3.80	0.39		

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
σ_{np}	133	120 - 130	5.31	0.48	1.042±0.037	[12]
		130 - 140	5.23	0.51		
		140 - 150	6.13	0.62		
		150 - 160	8.75	0.87		
	153	50.0	2.96	0.43	0.936±0.026	[13]
		56.0	2.14	0.40		
		65.5	2.59	0.40		
		68.0	2.34	0.18		
		76.5	1.98	0.22		
		83.0	1.98	0.19		
		89.5	2.29	0.18		
		98.0	2.71	0.31		
		99.5	2.51	0.19		
		124.5	4.04	0.28		
		138.0	6.19	0.26		
		149.0	6.88	0.43		
		159.0	7.98	0.13		
		165.0	8.59	0.29		
		171.0	10.04	0.20		
		174.0	9.68	0.47		
		176.0	10.65	0.46		
		178.0	10.69	0.54		

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
σ_{np}	150	63.2	2.70	0.12	1.004±0.026	[14]
		67.9	2.52	0.10		
		77.8	2.23	0.08		
		87.8	2.29	0.07		
		97.8	2.63	0.06		
		107.9	3.12	0.07		
		118.0	3.91	0.12		
		128.2	5.05	0.15		
		138.5	6.14	0.18		
		148.9	6.99	0.22		
		154.0	7.61	0.17		
		159.1	8.54	0.13		
		164.0	9.78	0.19		
		169.2	11.04	0.47		
		174.0	12.23	0.75		
		176.8	11.78	0.73		
σ^{np}_{tot}	147 interp.	0	52.16	1.1		[15]
P_{np}	140	20.7	0.283	0.027	1.000±0.037	[16]
		31.0	0.363	0.018		
		41.3	0.491	0.022		
		68.0	0.451	0.025		
		78.0	0.303	0.027		
		88.0	0.232	0.017		
		98.0	0.083	0.019		

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Norm	Ref.
P_{np}	140	108.0	0.032	0.013	1.000±0.037	[16]
		118.6	−0.038	0.012		
		128.6	−0.044	0.009		
		138.7	−0.059	0.009		
		149.0	−0.074	0.012		
		159.3	−0.037	0.012		
	143	41.0	0.475	0.039	0.990±0.050	[17]
		51.0	0.495	0.017		
		62.0	0.480	0.016		
		72.0	0.425	0.021		
		82.5	0.272	0.021		
		92.5	0.160	0.015		
		108.0	0.150	0.016		
		118.0	−0.020	0.016		
D_{pp}	142	12.4	−0.262	0.063		[18]
		20.7	−0.008	0.038		
		31.1	0.137	0.033		
		41.4	0.156	0.031		
		51.7	0.178	0.033		
		61.9	0.076	0.031		
		72.0	0.147	0.070		
		82.1	0.286	0.099		

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Ref.
D_{pp}	138	31.1	0.13	0.03	[10]
		41.4	0.19	0.06	
		61.9	0.23	0.13	
		82.1	0.36	0.20	
	143	31.0	0.082	0.077	[19]
		41.0	0.162	0.040	
		51.5	0.110	0.050	
		62.0	0.045	0.060	
		72.0	0.019	0.100	
		82.0	-0.037	0.133	
		92.0	-0.027	0.170	
R_{pp}	140	31.1	-0.252	0.030	[20]
		41.4	-0.227	0.028	
		51.7	-0.271	0.035	
		61.9	-0.146	0.037	
		72.0	-0.151	0.055	
		82.1	-0.047	0.080	
	141	24.0	-0.224	0.051	[21]
		32.7	-0.203	0.051	[22]
		45.7	-0.178	0.031	
		54.4	-0.212	0.042	
		67.2	-0.213	0.040	
		76.1	-0.147	0.063	
		84.0	-0.142	0.136	
		90.0	0.110	0.131	

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Ref.
A_{pp}	139	31.1	-0.368	0.032	[23]
		41.4	-0.344	0.031	
		51.7	-0.311	0.035	
		61.9	-0.231	0.046	
		72.0	-0.189	0.056	
		82.1	-0.099	0.079	
	143	32.2	-0.405	0.032	[24]
		43.2	-0.377	0.037	
		54.6	-0.342	0.050	
		65.0	-0.355	0.075	
		74.8	-0.198	0.079	
		84.8	0.022	0.154	
R'_{pp}	137.5	43.0	0.562	0.052	[25]
		52.5	0.472	0.054	
		62.0	0.376	0.068	
		72.5	0.238	0.084	
		82.1	0.251	0.121	
	140.4	31.4	0.625	0.062	[26]
		41.7	0.528	0.062	
		52.0	0.470	0.069	
		61.8	0.343	0.058	
		72.1	0.466	0.095	
		82.2	0.190	0.177	

Quantity	Energy MeV	Angle in deg. c.m.s.	Experimental value	Error	Ref.
C_{nn}^{pp}	143	90.0	1.00	0.05	[4]
		60.0	0.83	0.03	
R_{np}	137	42.1	0.169	0.100	[27]
		52.5	0.080	0.093	[28]
		62.9	-0.023	0.073	
		73.4	-0.151	0.095	
		83.6	-0.146	0.210	
A_{np}	135	42.1	-0.020	0.089	[27]
		52.5	0.070	0.074	[28]
		62.9	0.210	0.088	
		73.4	0.125	0.105	
		83.6	0.532	0.220	

Table 2

The phase-shifts in degrees /the Stapp parametrization/ for 147 MeV nucleon - nucleon scattering.

	$l_{max} = 3$	$l_{max} = 4$	$l_{max} = 5$	$l_{max} = 4$ the old set
f^2	0.058±0.003	0.057±0.005	0.067±0.011	0.062±0.007
Phase-shift	$\delta \pm \Delta\delta$	$\delta \pm \Delta\delta$	$\delta \pm \Delta\delta$	$\delta \pm \Delta\delta$
$^1S_0$	15.95 0.41	15.69 0.45	16.85 0.50	16.87 0.57
$^3S_1$	29.47 0.55	31.45 0.65	29.65 1.00	31.92 0.95
$^3P_0$	5.40 0.39	5.64 0.48	5.98 0.51	5.72 0.57
$^1P_1$	-20.90 1.05	-22.86 1.44	-12.37 2.35	-8.28 1.55
$^3P_1$	-17.10 0.13	-16.95 0.16	-17.00 0.17	-17.12 0.17
$^3P_2$	13.67 0.10	13.80 0.11	13.76 0.12	13.99 0.12
ε_1	1.26 0.80	-2.04 1.13	1.03 1.57	-2.15 0.13
$^3D_1$	-14.03 0.51	-15.87 0.58	-14.94 1.06	-17.11 0.96
$^1D_2$	5.70 0.08	5.62 0.14	4.91 0.21	5.36 0.30
$^3D_2$	24.48 0.72	21.11 1.26	26.44 1.01	25.38 1.26
$^3D_3$	2.26 0.46	3.51 0.54	-0.36 1.30	-2.52 0.66
ε_2	-2.60 0.06	-2.58 0.07	-2.50 0.09	-2.53 0.10
$^3F_2$	-0.08 0.20	-0.12 0.30	-0.04 0.26	0.03 0.30
$^1F_3$	-0.69 0.38	-0.67 0.74	-3.46 1.15	0.51 1.08
$^3F_3$	-1.77 0.17	-1.78 0.21	-1.91 0.19	-1.64 0.20
$^3F_4$	0.43 0.10	0.38 0.15	0.47 0.16	0.52 0.16
ε_3		4.23 0.47	3.62 1.01	1.21 0.73
$^3G_3$		-0.11 0.56	-3.02 0.89	-4.40 0.50
$^1G_4$		0.46 0.07	0.72 0.09	0.75 0.11
$^3G_4$		0.83 0.51	5.15 0.93	6.10 0.82
$^3G_5$		-1.25 0.23	-0.19 0.32	-0.35 0.29
ε_4			-0.70 0.06	
$^3H_4$			0.14 0.12	
$^1H_5$			0.22 0.59	
$^3H_5$			-0.50 0.13	
$^3H_6$			0.17 0.08	
χ^2	445.20	392.75	365.62	173.4
$\chi^2/\overline{\chi^2}$	1.40	1.25	1.13	0.94

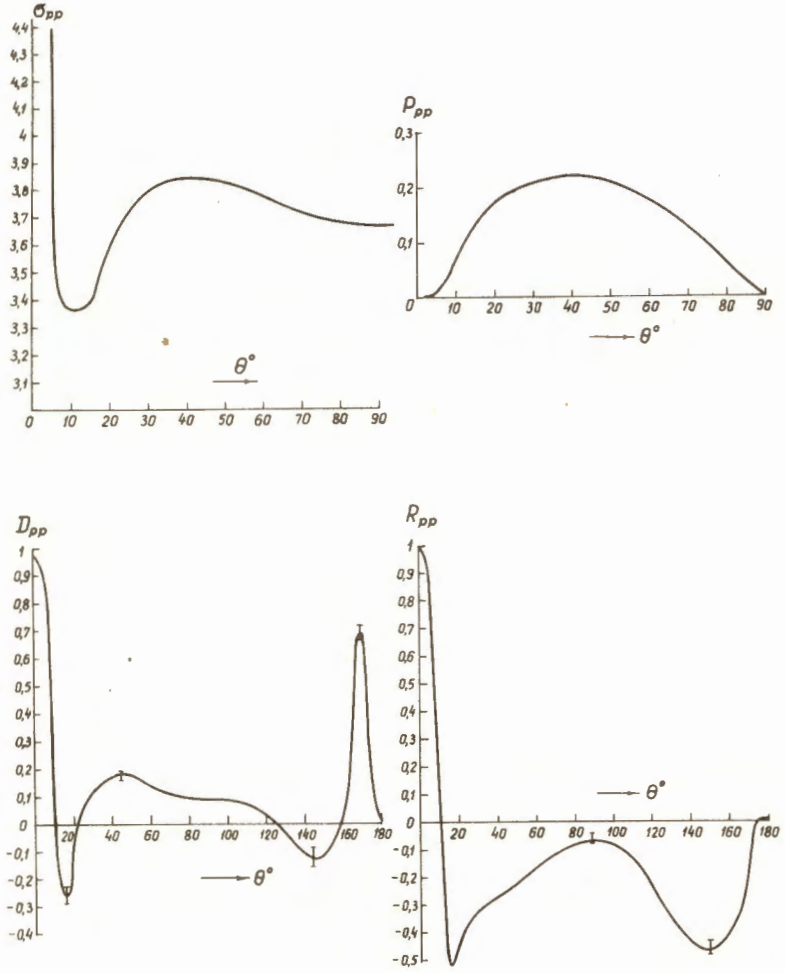
σ_{pp}
4,4
4,3
4,2
4,1
4
3,9
3,8
3,7
3,6
3,5
3,4
3,3
3,2
3,1
θ°
0 10 20 30 40 50 60 70 80 90
P_{pp}
0,3
0,2
0,1
0 10 20 30 40 50 60 70 80 90
θ°
D_{pp}
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
20 40 60 80 100 120 140 160 180
θ°
R_{pp}
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,5
θ°
20 40 60 80 100 120 140 160 180

Fig. 1.

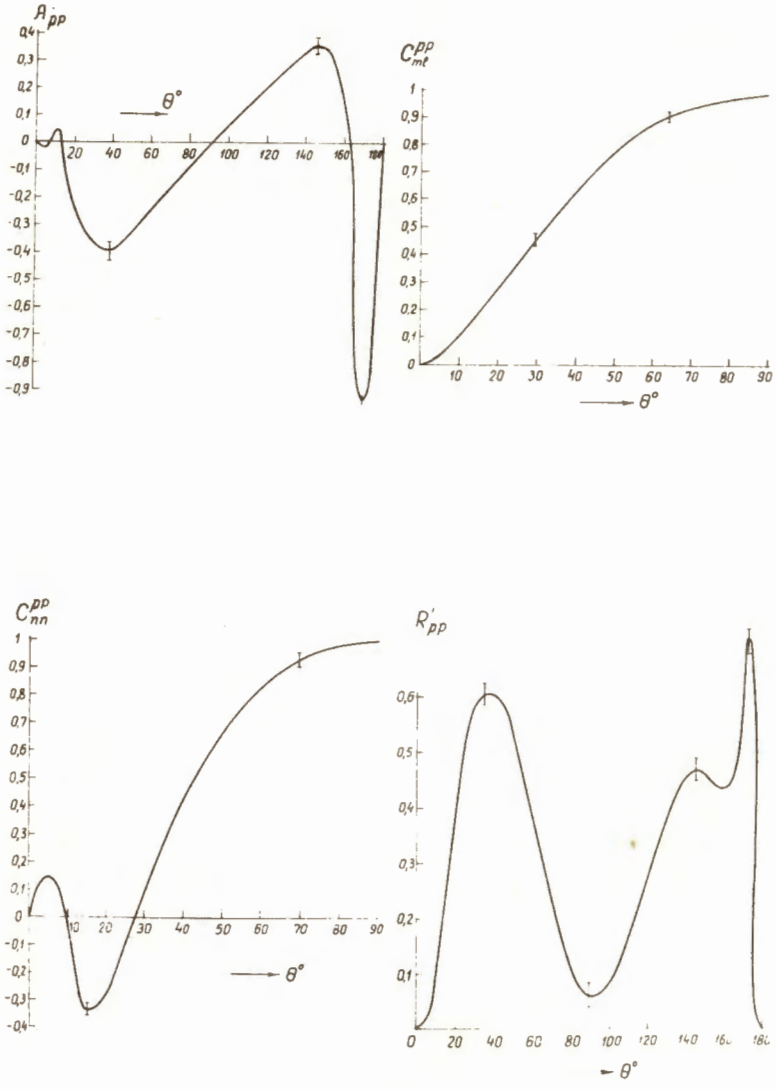
A_{pp}
θ°
C_{mt}^{pp}
θ°
C_{nn}^{pp}
θ°
R'_{pp}
θ°

Fig. 2.

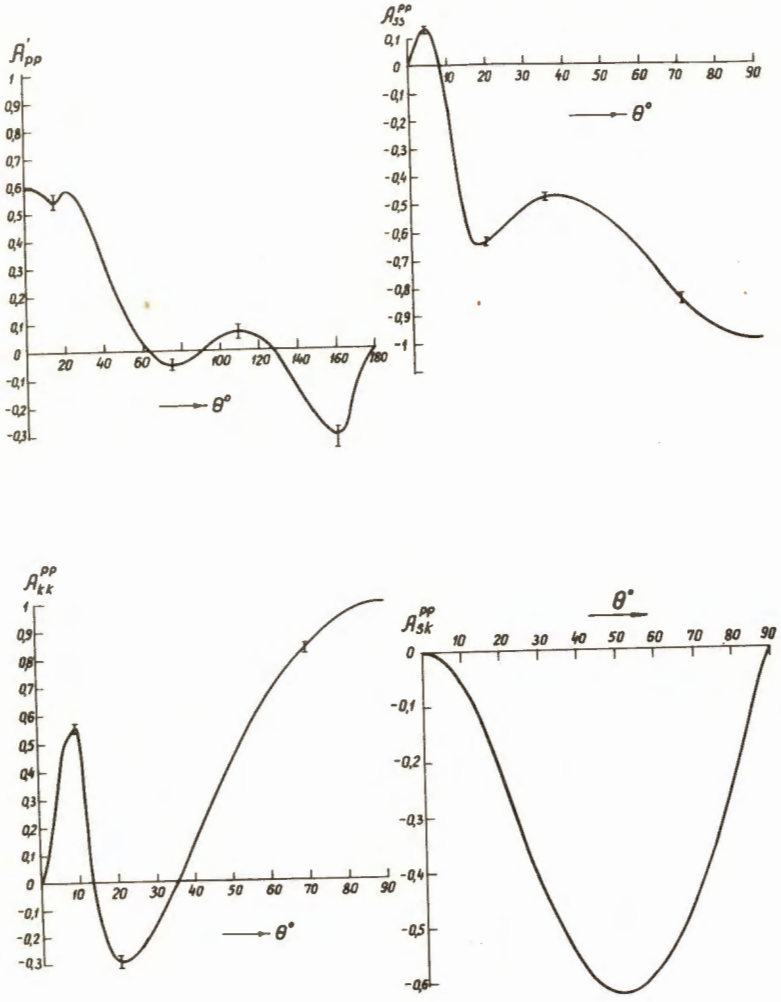

Fig. 3.

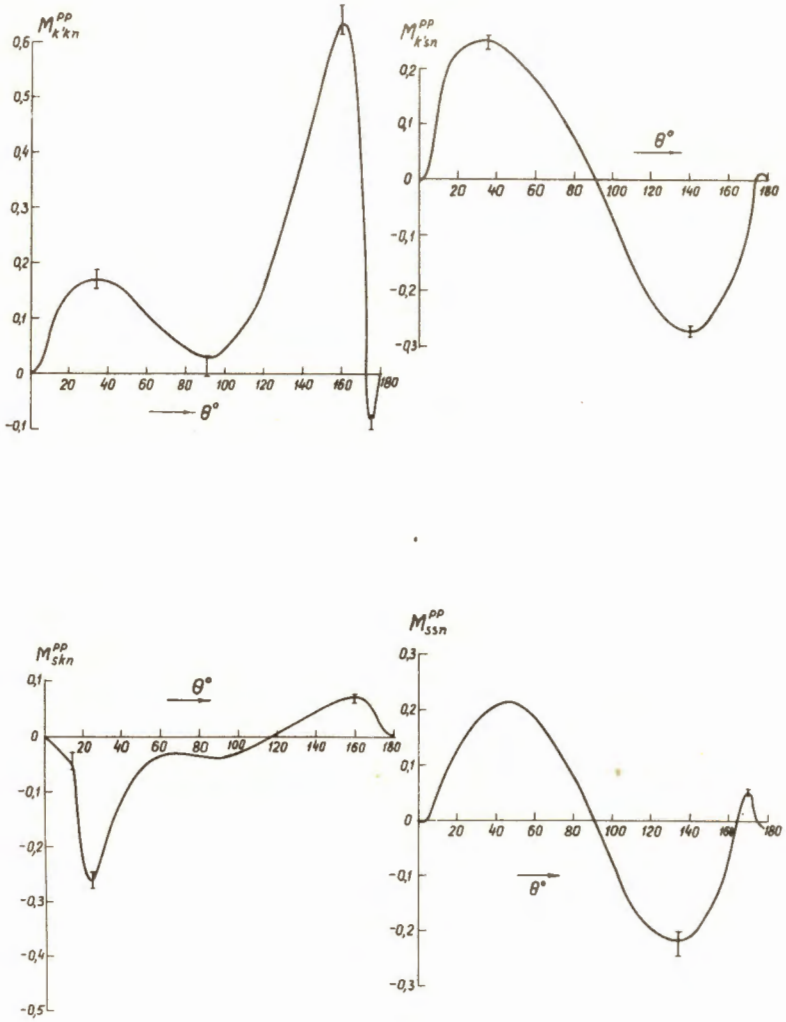

Fig. 4.

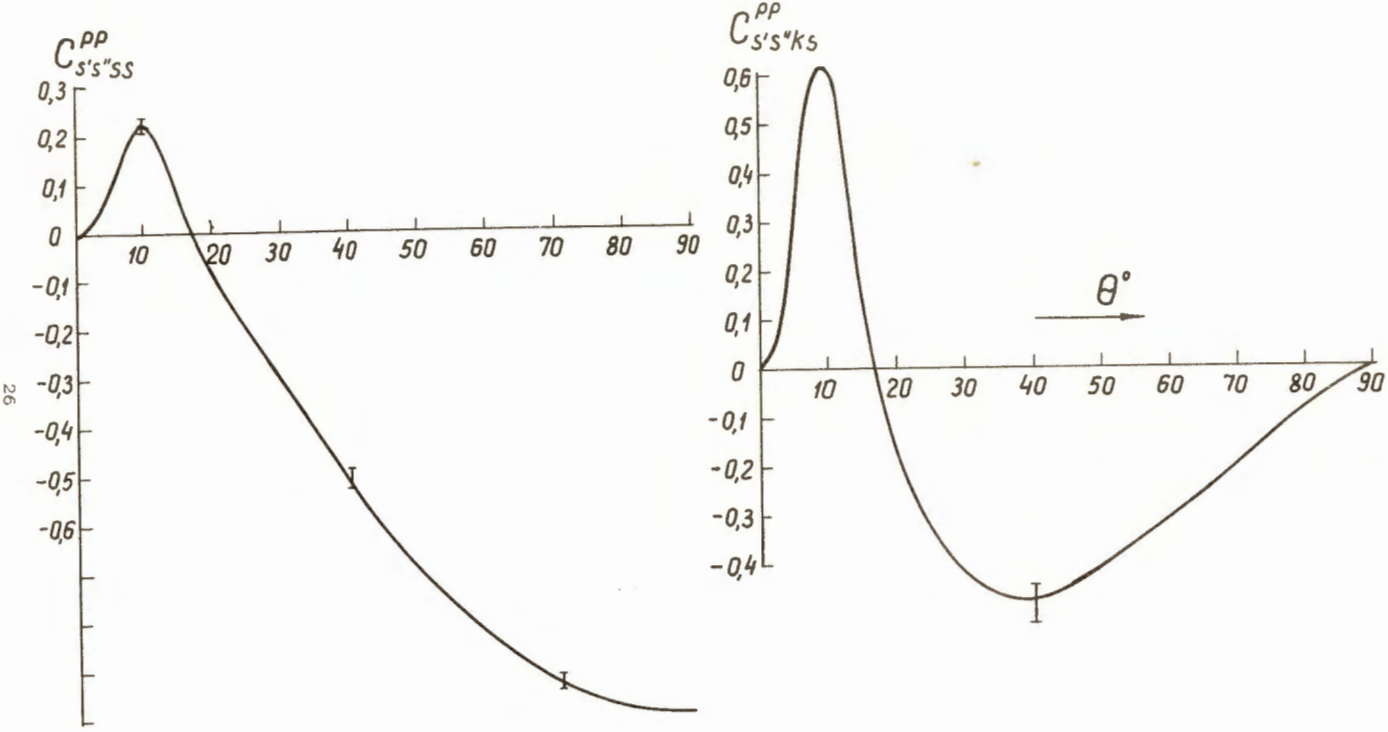
$C^{pp}_{s's''ss}$
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,5
-0,6
10
20
30
40
50
60
70
80
90
$C^{pp}_{s's''ks}$
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
θ°
10
20
30
40
50
60
70
80
90

Fig. 5.

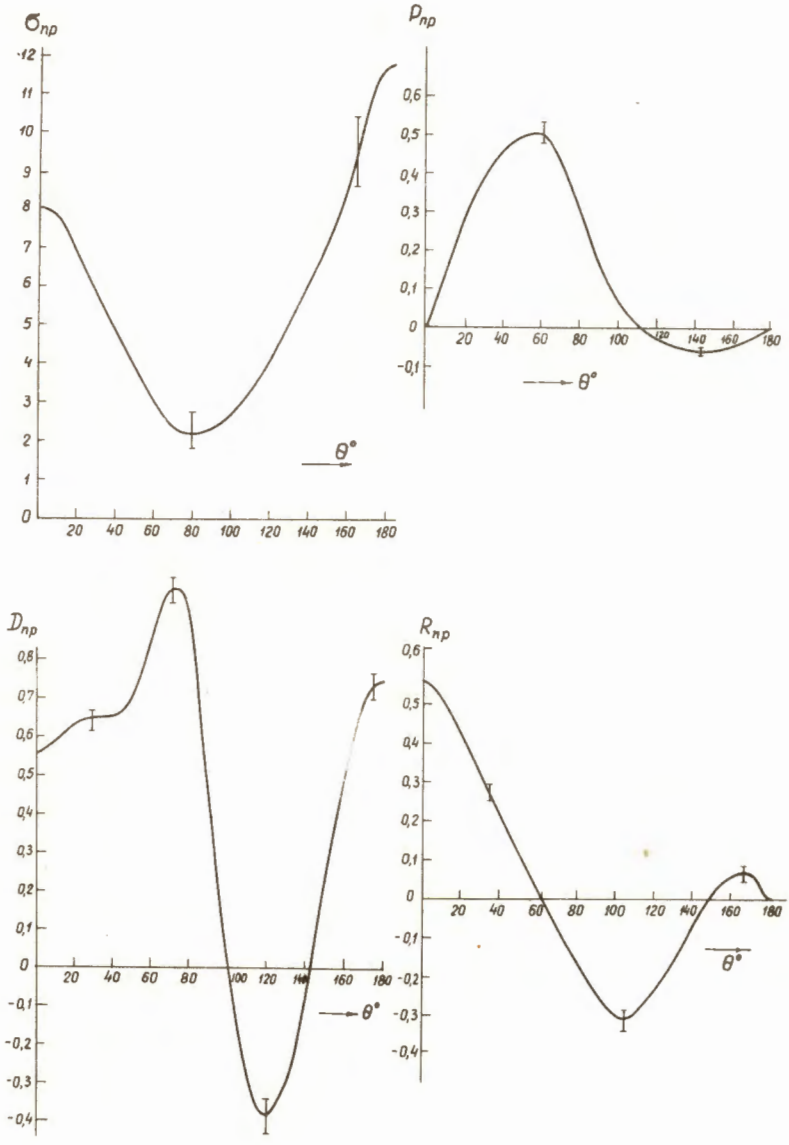

Fig. 6.

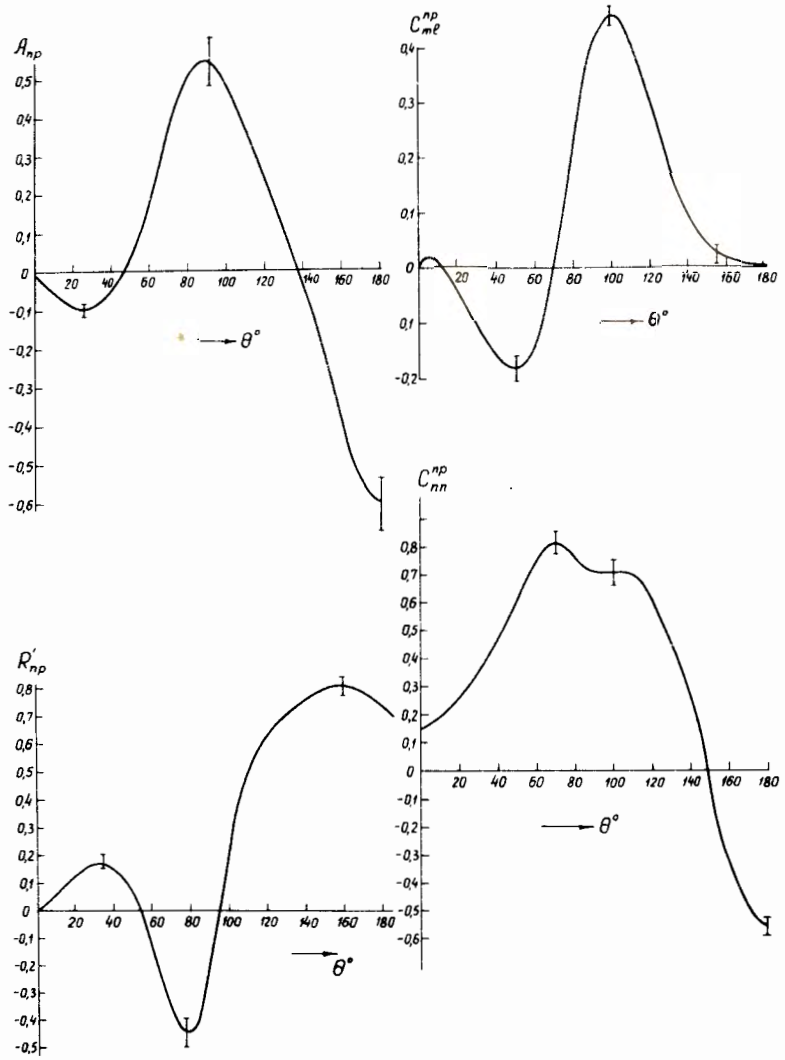

Fig. 7.

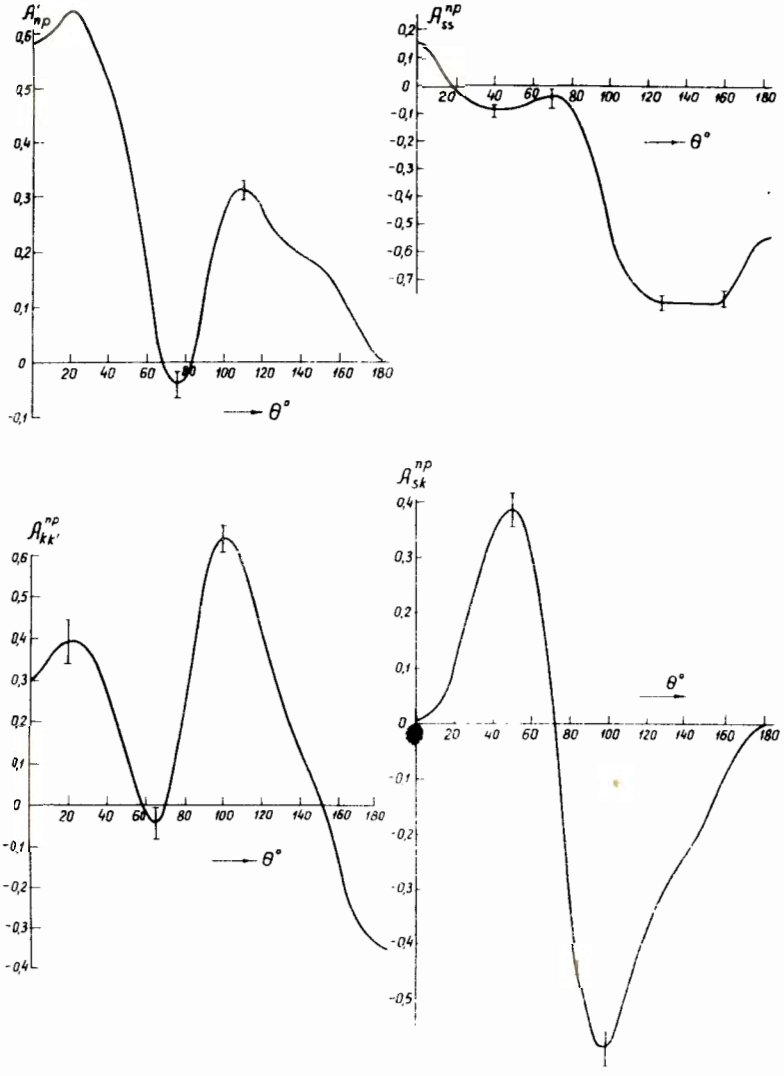

Fig. 3.

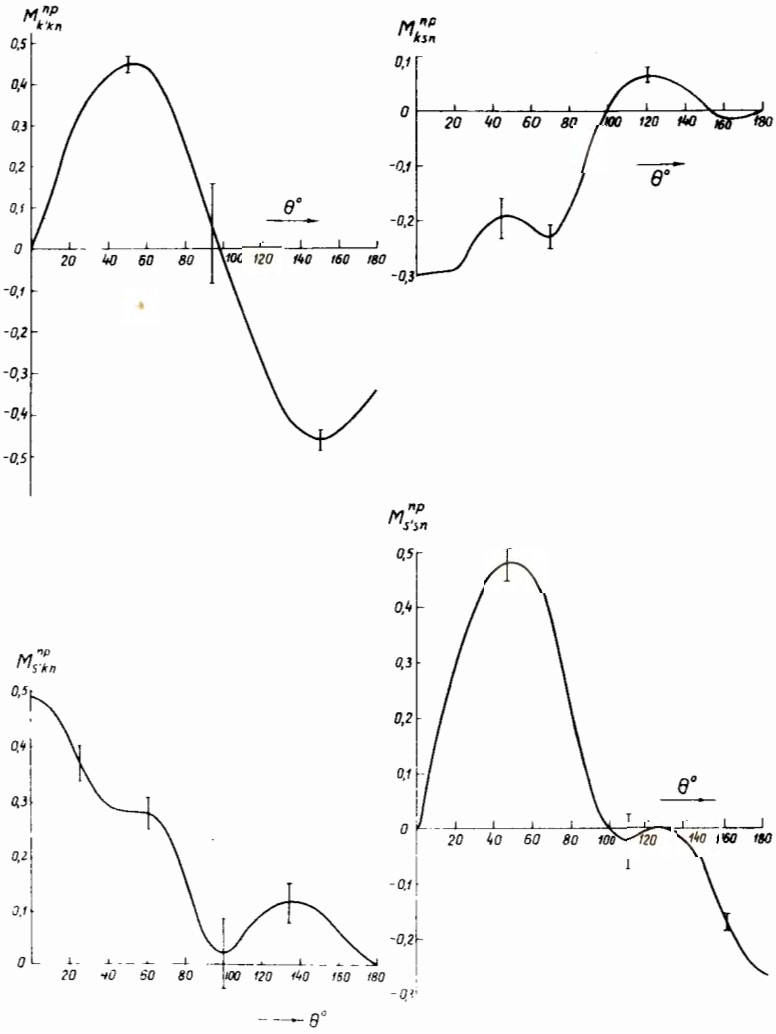

Fig. 5.

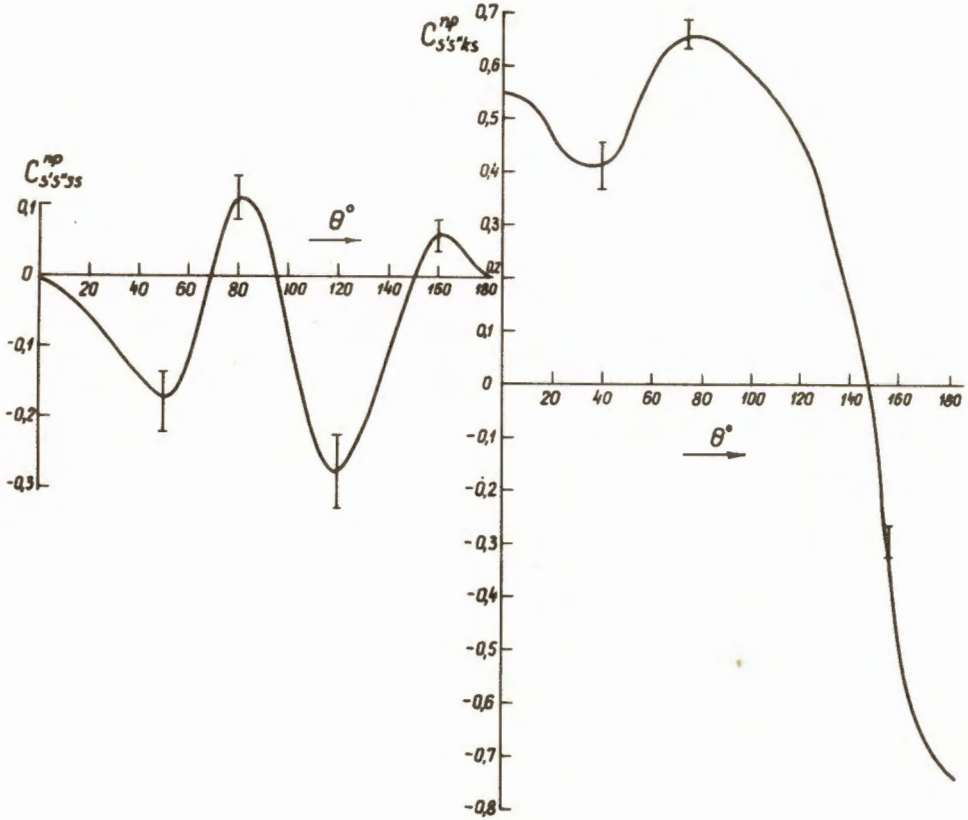
$C^{пр}_{s's''ks}$
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,5
-0,6
-0,7
-0,8
20
40
60
80
100
120
140
160
180
θ°
$C^{пр}_{s's''ss}$
0,1
0
-0,1
-0,2
-0,3
20
40
60
80
100
120
140
160
180
θ°

Fig. 10.