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The results of measurement of the depolarization parameter in the polarized proton beam scattering by protons at angles 54,72, 108 and 126° in the centre-of-mass system are reported. In scattering at angles 54, 72 and 90° the normal component of proton beam polarization changes only slightly. The sum and the difference of depolarization parameter values for scattering angles symmetrical relatively to the direction of 90° are interpreted in terms of the amplitudes of pp-scattering matrix.

INTRODUCTION

The previous experiments have shown that the polarized proton beam scattering by protons at 640 MeV at an angle of 90° in the centre-of-mass system (c.m.s.) causes weak depolarization of the beam/1/. This result witnesses that at this energy the pp-interaction , connected with elastic scattering at large angles is comparatively seldom accompanied by changes of spin orientation. Further information, concerning the character of pp-interactions, can be obtained from experiments in which the depolarization parameter is measured at scattering angles both above and below 90° (c.m.s.), that has been realised in the present work. Results of such measurements give two independent relations between the amplitudes of pp-scattering matrix in addition to two relations, corresponding to the data on angular dependence of differential cross sections and to those of polarization.

The experiments in question have been performed at the 6-meter synchrocyclotron of the Joint Institute for Nuclear Research in accordance with the programme of pp-interaction studies at 660 MeV.

PROCEDURE OF MEASUREMENTS AND RESULTS

The scheme of the experiment, plotted in Fig.1, was the same in general features as in the preceding experiments (see Fig. 1a in/1/). The proton beam with the polarization $P = 0.58 \pm 0.03$ *and the energy of* 640 ± 12 *MeV, scattered inside the synchrocyclotron chamber to the left at an angle of 9° in the berillium target-polarizer, has been used. The second scattering took place in a cylindrical container 12 cm in diameter, filled with liquid hydrogen. In the centre of the liquid hydrogen target the average proton energy was equal to 635 MeV, the density of the beam 3 cm in diameter was* 7.10^5 *proton/cm*^{2} *sec.*

The depolarization parameter D was measured at 18° interval of the scattering angle θ_2 *ranging from 54° up to 126°. The beam of protons, second-scattered to the left at an angle of* θ_2 *was determined by a three-counter telescope* C_1, C_2 ,C_3. *In order to separate elastic pp-scattering from the accompanying inelastic processes, which take place in the liquid hydrogen target, the scattered and recoil protons were registered by the conjugated telescope* C_1, C_2, C_3 *and* C_8, C_9, *the angle of divergence between them was corresponding to the kinematics of elastic pp-collisions.*

The normal component of the polarization vector of the second-scattered protons was determined by measuring the left-right asymmetry ε_{3n} of the charged particles emmited in the direction of $\theta_3 = 12^{\circ}$ (lab. system) from the carbon target-analyser R_3. These measurements consisted in the registration of ninefold coincidences of impulses from the counters, grouped into the telescopes C_1, C_2, C_3 and C_8, C_9 and the counters of the telescope C_4, C_5, C_6, C_7, detecting triply scattered protons.

In the registered number of ninefold coincidences the corrections were introduced which took into account a) accidental ninefold coincidences ($\sim 1\%$), b) the effect of the empty container ($\sim 3\%$). In order to be convinced that the angles θ_3, counted to the left and to the right are really equal and, consequently, there is no possibility of appearing false asymmetry owing to difference of zero reading of the scale of θ_3 with the effective axis of the secondary beam, the profile of the second-scattered protons of the beam was carefully measured at all the angles of measurement. The procedure of these experiments was analogous to that which had been used earlier by Berkely group[2]

The depolarization parameter $D(\theta_2)$ was found from the relation[3]:

$$D = \frac{\varepsilon_{3n}}{\varepsilon_3} \left(1 + P_1 P_2 \right) - \frac{P_2}{P_1} \quad , \qquad (1)$$

where P_1 is the initial polarization of the beam, P_2 is the polarization, arising in the unpolarized proton beam scattering in hydrogen at a given angle θ_2. The magnitude and angular dependence of P_2 are known from the previous measurements[4].

ε_3 is the left-right asymmetry, observed experimentally in the emission of the charged particles from the carbon target, bombarded by the proton beam with the polarizations P_1 and the energy equal to that of protons, scattered in hydrogen at an angle of θ_2. In the measurements of this asymmetry the same technique was used as in the measurements of ε_{3n}. The counters C_1, C_2, C_3 and the carbon target were installed in the primary polarized proton beam, the energy of which was reduced to that of the second-scattered proton beam by means of a filter, made of lead and polyethelene plates. Particles, emitted from the carbon target in the direction of 12°, were registrated by the telescope C_4, C_5, C_6, C_7, switched in coincidence with the telescope C_1, C_2, C_3. Simultaneously the intensity of the primary beam was reduced 50-100 times. It is necessary to mark that measurements, performed with slowing down filters, which had different ratio between the thickness of lead and polyethelene layers, gave values which are in agreement within standard deviations.

At each angle of observation 10-12 independently repeated measurements of the asymmetries ε_{3n} and ε_3 were performed. In the overwhelming majority of cases the results of the repeated measurements coincided within experimental errors. Data on average energies and also on angle divergence of protons in the second-scattered beams are listed in the table together with experimentally measured asymmetries ε_{3n} and ε_3 and their statistical errors. The obtained values of the depolarization parameter for different scattering angles are also listed there.

Table

The values of the asymmetries $\mathcal{E}_{3n}$, $\mathcal{E}_3$ and those of the depolarization parameter D (for $\theta_2 = 90^\circ$ the results are taken from [1])

$\theta_2 \pm \Delta\theta_2$	$E_2 \pm \Delta E_2$ MeV	$\mathcal{E}_3 \pm \Delta\mathcal{E}_3$	$\mathcal{E}_{3n} \pm \Delta\mathcal{E}_{3n}$	$D \pm \Delta D$
54° ± 4°	490 ± 20	0.121 ± 0.005	0.161 ± 0.024	0.99 ± 0.25
72° ± 4°	416 ± 21	0.173 ± 0.008	0.164 ± 0.029	0.69 ± 0.20
90° ± 5°	315 ± 20*	0.216 ± 0.012	0.200 ± 0.032	0.93 ± 0.17
108° ± 5°	219 ± 27	0.198 ± 0.011	–0.023 ± 0.033	0.28 ± 0.16
126° ± 5°	125 ± 21	0.157 ± 0.015	–0.009 ± 0.036	0.57 ± 0.20

DISCUSSION

According to Wolfenstein[3] the depolarization parameter can change in the limits of $-1 + 2|P_2| \leq D \leq +1$. The results, obtained in these experiments, show that the depolarization parameter, corresponding to pp-scattering at angles 54,72,90,108 and 126°, has a positive value. Moreover, for angles 54,72 and 90° the value of the depolarization parameter was found to be near +1. Comparing the asymmetry values $\mathcal{E}_{3n}$ and $\mathcal{E}_3$, obtained for angles 54°,72° and 90°, one can see that in pp-scattering at these angles the normal component of polarization does not undergo considerable changes.

*Earlier the systematic measurements of the depolarization parameter in pp-scattering had been performed at 315[5] and 143[6] Mev for angles less than 90°. In both cases the obtained values of the depolarization parameter had a positive sign**. The comparing of the available data on triple proton scattering shows that with the increase of the energy from 143 up to 635 MeV in the interval of the scattering angles of $50^\circ \leq \theta_2 \leq 90^\circ$ there appears a tendency to the increase of the depolarization parameter. Indications on this feature of pp-interaction in the energy range under study had been more convincing if the measurements*

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* *In[1] it is pointed out by mistake that the energy divergence of the second-scattered protons is ± 40 MeV, in reality it is ± 20 MeV.*

** *The Harwell group[7] has found negative value of the depolarization parameter for angles in the interval of $50^\circ \leq \theta \leq 90^\circ$ on observing depolarization in pp-scattering at 142 MeV. This result, however, was not confirmed (see[6]). It is necessary to mark that the sign of the depolarization parameter is extremely sensitive to nuclear potential models used. Thus, the values of the depolarization parameter, found in[6], are in agreement with the calculations of Gammel and Thaler who have used the static potential with the addition of $\vec{L}\cdot\vec{S}$-term while the use of the Signell-Marshak potential[9] leads to the value of the depolarization parameter, differing even by the sign from that, given by the experiment.*

of the depolarization parameter had been performed with a better accuracy and with less energy intervals.

If one writes the matrix of pp-scattering in notations of work[3],

$$M = BS + C(\vec{\sigma}+\vec{\sigma}_t)\vec{n} + \frac{1}{2}G[(\vec{\sigma}\vec{K})(\vec{\sigma}_t\vec{K}) + (\vec{\sigma}\vec{p})(\vec{\sigma}_t\vec{p})]T + $$
$$+ H[(\vec{\sigma}\vec{K})(\vec{\sigma}_t\vec{K}) - (\vec{\sigma}\vec{p})(\vec{\sigma}_t\vec{p})]T + N(\vec{\sigma}\vec{n})(\vec{\sigma}_t\vec{n})T \qquad (2)$$

and expresses the differential cross section of the unpolarized proton beam scattering by protons $\sigma_o(\theta)$ and the depolarization parameter $D(\theta)$ by the complex amplitudes B, C, G, H and N in the following form:

$$\sigma_o(\theta) = \frac{1}{4}|B|^2 + 2|C|^2 + \frac{1}{4}|G-N|^2 + \frac{1}{2}|N|^2 + \frac{1}{2}|H|^2, \qquad (3)$$

$$\sigma_o(\theta)[1 - D(\theta)] = \frac{1}{4}[G-N-B]^2 + |H|^2, \qquad (4)$$

then keeping in mind that B, $C/\sin\theta$ and H are even and G and N are odd functions of cos θ, it is not difficult to show that the values of the depolarization parameter for angles symmetrical relatively to the direction of 90°, are connected by the following two independent relations with the amplitudes of the scattering matrix:

$$\sigma_o(\theta)[D(\theta) + D(\pi-\theta)] = 4|C|^2 \mp |N|^2 - |H|^2, \qquad (5)$$

$$\sigma_o(\theta)[D(\theta) - D(\pi-\theta)] = Re\,\{[G-N]B^*\}. \qquad (6)$$

Hence, it is seen that the product of the differential cross section $\sigma_o(\theta)$ by the sum $[D(\theta) + D(\pi-\theta)]$ is represented only by the triplet amplitudes C, N and H, whereas the product of the differential cross section $\sigma_o(\theta)$ by the difference $[D(\theta) - D(\pi-\theta)]$ is wholly caused by singlet-triplet interference.

Basing on the results of the present experiments, one can state with confidence that in pp-scattering at 660 MeV the sum $[D(\theta) + D(\pi-\theta)]$ is not equal to zero. It means that in pp-scattering matrix a great role is played by the triplet terms $C(\vec{\sigma}+\vec{\sigma}_t)\vec{n}$, $H[(\vec{\sigma}\vec{K})(\vec{\sigma}_t\vec{K}) - (\vec{\sigma}\vec{p})(\vec{\sigma}_t\vec{p})]$ and $N(\vec{\sigma}\vec{n})(\vec{\sigma}_t\vec{n})$.
As it has been mentioned already in[1] from the fact that D(90°) is near +1, it follows that the term $C(\vec{\sigma}+\vec{\sigma}_t)\vec{n}$ gives the main contribution into scattering at an angle of 90°.

In order to find out whether the difference between the observed values $D(\theta)$ and $D(\pi-\theta)$ is valuable or it is accidental, it was necessary to analyse the character of distribution of all *the errors of the measured asymmetries ε_{3n} and ε_3 , and also of the polarizations P_1 and P_2. The result of statistical analysis is as follows: the probabilities, that the difference $[D(54^\circ) - D(126^\circ)]$ and $[D(72^\circ) - D(108^\circ)]$ by the module differ from zero, are 80% and 86%, respectively. Both the differences between the observed values of the depolarization parameter are practically independent of each other and the probability that the accidental deviation of both the differences from the average value, equal to zero, which takes place simultaneously, makes up 3% only.*

Thus, though the accuracy of the data of the present experiments is poor, these data, however, indicate that in the treated region of energy and of scattering angles the singlet-triplet interference takes place, hence, it follows that the final states of pp-system include some mixture of singlet states.

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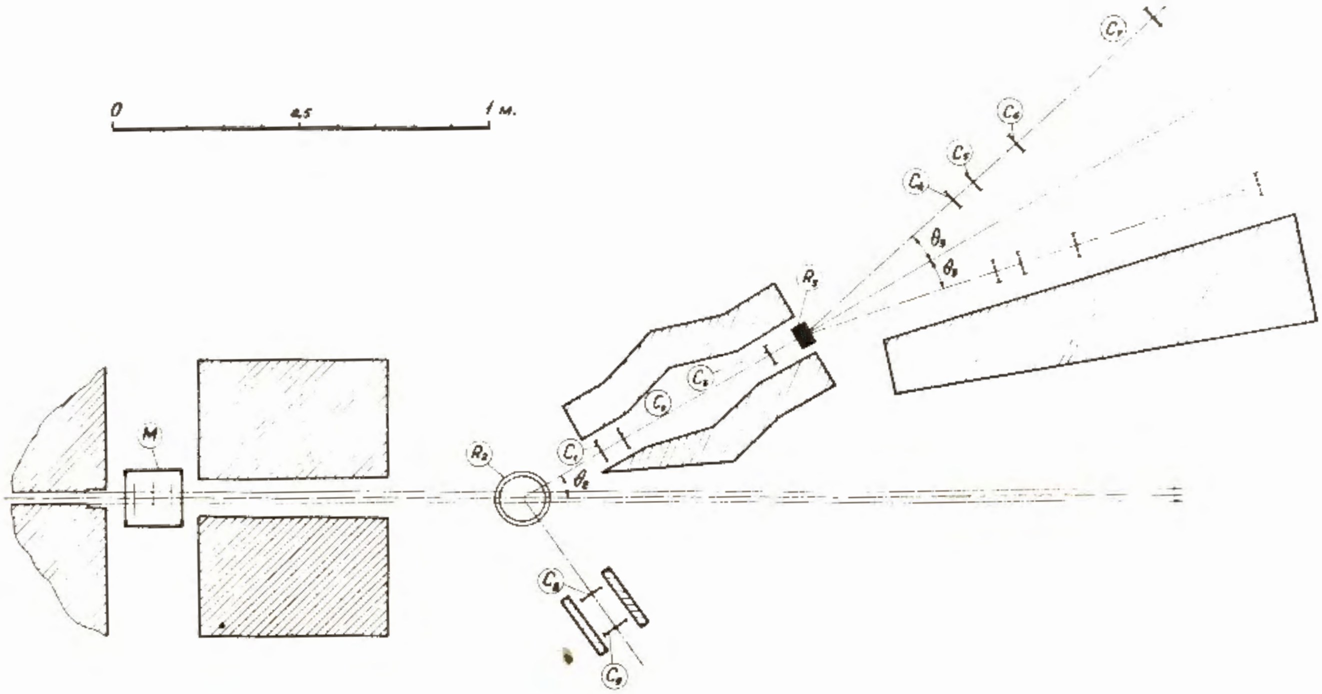

Fig. 1. *The scheme of arrangement of the scatterers and the registrating equipment in the scattering plane.* M *is the monitor,* R_2 *is the second scatterer (a container with liqiud hydrogen),* R_3 *is the third scatterer (a graphite block 5 x 5 cm*^{2} *in section and 6 cm thick),* $C_1 \ldots C_9$ *are scintillation counters which had sizes 6 .5 x 6.5 , 6 x 7 , 6 x 7, 6 x 6, 6 x 6.5, 6.5 x 7, 6.5 x 6.5, 7.5 x 12, and 8.5 x 13 horisontally and vertically, respectively, and 6mm thick. The measurements of D(126°) were fulfilled without the counters* C_2 *and* C_5*, and simultaneously, the third scatterer 5 x 5 cm*^{2} *in section and 3 cm thick was used. The dashed curve shows the location of the lead shielding.*