$\omega_k^2 \sim Z^8$, while $W(M1; 2s \to 1s)$ grows rapidly ($\sim Z^{10}$). Thus, the effect of $\langle W_{st} \rangle$ falls off; but also for an isolated mesic ion the effect of neutral interaction diminishes with increasing Z.

5. In contrast to other mesic neutral μH can penetrate deeply into the shell of the atom of the medium, and in this case the process of $E0$ conversion of the $2s\frac{1}{2} \to 1s\frac{1}{2}$ transition of μH in the shell of an atom of the medium is possible. In the Born approximation we obtain for the damping of the population of the $|2s\frac{1}{2}\rangle$ level of μH moving along a straight line trajectory in a hydrogen medium

$$\langle W(E0)\rangle \approx \pi\rho a_0^3 \frac{e^2}{\hbar a_0} 2\cdot 3^{1/2} \left(\frac{m}{m_\mu}\right)^4 \left(\frac{m_\mu}{m}\right)^{1/2}. \tag{64}$$

Of greater significance turns out to be the Stark effect of the intra-atomic field. In the model utilizing straight line trajectories in the case of a collision of μH and an atom of hydrogen of the medium we obtain as a result of a numerical calculation assuming $x_0 = a_0/4$ where the condition of the weak field (56) is still satisfied

$$\langle W_{st}(E)\rangle > \rho a_0^3 14\pi\lambda \left(\frac{b}{\omega}\right)^2 \approx 1.15\cdot 10^{13}\rho a_0^3 \ [\mathrm{sec}^{-1}].$$

For a density of $\rho = 10^{19}$ at/cm^3 $\langle W_{st}\rangle \geq 1.7\times 10^7$ sec^{-1}, while $W(M1; 2s \to 1s) = 4.6\times 10^{-4}$ sec^{-1}. Consequently, the Stark effect of the intra-atomic field of the atoms of the medium practically does not allow us to observe the effect of the neutral weak interaction in a μH system for medium densities of $\rho \geq 10^{11}$ at/cm^3. The estimates given above provide evidence of very rigorous limitations on the conditions of carrying out an experiment which are imposed by the Stark effect in the act of collision, and therefore the values of $\langle W_{st}(\mathbf{E})\rangle$ have to be calculated more accurately.

When a μH atom passes through a H_2 molecule the intra-atomic field acts on the average over a greater part of the trajectory than in the case of passage through an atom of hydrogen. Correspondingly the allowable density of H_2 gas must be lower than the one obtained in the estimate for atomic hydrogen.

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Measurement of the polarization correlation coefficient C_{nn}^{pp} in elastic *pp* scattering at 610 MeV

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We measured the polarization correlation coefficient C_{nn} in elastic *pp* scattering at an energy 610 ± 10 MeV at four c.m.s. scattering angles (40, 67, 78, and 90°). We used in the experiments a polarized proton beam with maximum polarization 0.39 ± 0.02 and a polarized proton target of the frozen type. The maximum polarization of the target was 0.97 ± 0.04.

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The main reasons that induced us to measure the correlations of the polarization in elastic *pp* scattering at 610 MeV were the following:

1. The ambiguity in the determination of the amplitude of the elastic *NN* scattering at 630 MeV. If it is assumed that the one-pion approximation is valid in elastic *NN* scattering starting with orbital angular momenta $l \geq 7$, then a phase-shift analysis at this energy yields at least two equally probable (in the sense of the χ^2 criterion) solutions.[1] The simplest way of discriminating between these solutions is to measure C_{nn}^{pp} with a relative error $\sim 10\%$.

2. The previously observed maximum, at 600–700 MeV, in the energy dependence of C_{nn}^{pp} in scattering through an angle of 90° (c.m.s.), which may point to

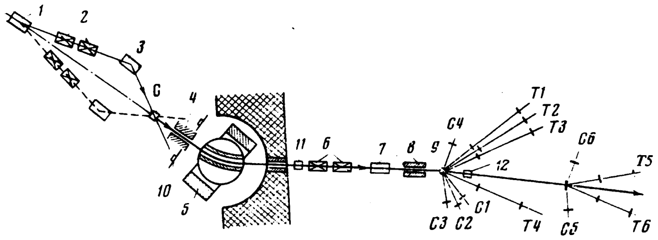

FIG. 1. Experimental setup (the symbols are explained in the text).

the presence of some anomaly of the pp interaction at these energies.

3. The possibility of verifying under real accelerator-experiment conditions the characteristics of the new "frozen" polarized proton target produced in the Nuclear Problems Laboratory of JINR under the leadership of B. S. Neganov on the basis of the method of dissolving He^3 in He^4.

EXPERIMENTAL SETUP

To determine C_{nn}^{pp} we used in the experiment the scattering of a polarized proton beam by a polarized proton target. The experimental setup is shown in Fig. 1. The unpolarized proton beam extracted from the JINR synchrocyclotron ($E = 650$ MeV) passes through a bending magnet 1, is focused by lens 2, and is guided by magnet 3 to a carbon target C. The beam of protons scattered by the carbon target has in this case a polarization 34–39%. This polarized proton beam is shaped subsequently by collimator 4, is focused by a hard-focusing magnetic channel between the poles of magnet 5, and is directed with the aid of this magnet into a collimator located in the shielding wall of the accelerator (collimator diameter 3 cm, length 4 m). After going through the collimator, the polarized beam is focused by a magnetic lens 6, passes through a bending magnet 7, and is incident through collimator 8 on the polarized proton target 9.

The scattered protons emitted from the polarized target at angles $\vartheta = 40$, 67, 78, and 90° (c.m.s.) are registered by telescopes T1–T4, each made up of two scintillation counters and connected for coincidence with the recoil-proton counters C1–C4. The primary proton beam is monitored by a block of three small ionization chambers 10. The beam profile at the polarizer is monitored by spark chambers with analog information display. The polarized beam is monitored by two ionization chambers 11 and 12. The profile of the polarized beam is monitored by a thin movable (in steps of 0.5 cm) scintillation counter, which is installed at a given point on the beam axis and moves across the beam.

At the end of the path of the polarized beams is mounted a polarimeter that measures the polarization of the beam. The polarimeter consists of two telescopes T5 and T6 connected for coincidence with recoil-proton counters C5 and C6. To determine the polarization of the beams, the asymmetry in the elastic pp scattering through 20° (l.s.) is measured by determining the difference due to effects from polyethylene (CH_2) and graphite (C) targets.

The data from the outputs of all the detectors were fed to an HP-2116 computer through a KAMAK crate containing the required number of counters. The data were fed to the computer every 300 sec. The use of the HP-2116 computer has made it possible, besides recording the data from the detectors, to monitor the constancy of the beam intensity measured by different monitors and the constancy, within the limits of the statistical deviations, of the counting rate of the detectors, as well as record the entire necessary service information thus greatly facilitating the subsequent reduction of the measurement results.

The polarized proton target (PPT) consisted of minute spheres of propanediol (diameter 2 mm), placed in a stainless steel container of 3 cm diameter and 3 cm height; the container wall thickness was 0.1 mm. The target contained 1.2 g of hydrogen and 9.8 g of carbon. The container with the propanediol was placed in a magnetic field produced by two superconducting coils (coil diameter 40 cm, gap between them 3 cm). The aperture of the particle exit window was ±70°, and the diameter of the entrance window was 7 cm. The entrance and exit windows were covered with copper-foil screen 20 μ thick and with mylar 200 μ thick. The refrigerator of the target operated on the basis of the principle of dilution of He^3 in He^4. The main parameters of the polarized proton targets are the following.

Volume of target 14 cm^3, working medium—propanediol ($C_3H_8O_2$).

Maximum polarization 0.97 ± 0.04, rate of "pumping" of the polarization 0.90 hr^{-1}.

Working temperature: when "pumping" the polarization 0.3–0.4 °K, in the "frozen" regime 0.04 °K.

Polarization relaxation time in a field 26 kOe at 0.04 °K—about 1000 hours.

Cooling capacity of the refrigerator at 0.4 °K—15 mW; He^3 circulation rate—3×10^{-3} mole/sec.

Magnetic field $H = 26$ kOe, homogeneity of magnetic field in the target volume $\Delta H/H = 10^{-4}$.

The hydrogen-free equivalent of the PPT was activated charcoal placed in a container equivalent to the PPT container. The hydrogen-free equivalent was placed in the PPT cryostat (in place of the propanediol) at the end of each measurement run.

The polarized proton beam was obtained by scattering a beam of unpolarized 650-MeV protons by carbon through an angle 6.3°. The beam dimensions at the polarizer were 5 cm (width at half height) in the horizontal direction and 4 cm in the vertical direction. The beam divergence was 1.2° in the horizontal plane and 10.5° in the vertical plane. The maximum shift of the center of gravity of the beam on the polarizer during the time of one measurement run did not exceed 2 mm.

The intensity of the polarized beam was 3×10^5 proton-cm^2 sec^{-1}, and the polarization was 0.39 ± 0.02. The

TABLE I.

Run number	Type of asymmetry measurement	Asymmetry value				Experimental conditions			
		$\vartheta=40°$	67°	78°	90°	P_B	P_T	τ	β
1	$\varepsilon_{+-,-}$	–	0.070 ±0.008	–	--0.120 ±0.010	0.38	0.60	0.06	
2	$\varepsilon_{+-,-}$	−0.545 ±0.008	0,126 ±0.008	0.016 ±0.005	−0.168 ±0.006	0,34	0.87	−0.04	
3	$\varepsilon_{+-,+-}$	0.210 ±0.016	0.177 ±0.006	0.194 ±0.007	0.190 ±0.006	0.39	0.89	0.03	0.10
4	$\varepsilon_{+-,+-}$	0.166 ±0.015	0.166 ±0.006	0.161 ±0.006	0.179 ±0.006	0.39	0.89	0.03	0.19

beam dimensions at the PPT were 2.5×2.5 cm. The beam axis was determined by measuring its profile in the horizontal plane at two points 2 m apart. The accuracy of the setting of the beam direction was 2×10^{-3} rad. The proton energy in the beam was 610±10 MeV.

The number of particles registered by the detector when the polarized beam was scattered by the polarized target and the beam and target polarizations were perpendicular to the scattering plane is given by the expression

$$Id\omega=I_0[1+(\mathbf{P}_B+\mathbf{P}_T)\mathbf{P}_{pp}+C_{nn}\mathbf{P}_B\mathbf{P}_T]d\omega, \qquad (1)$$

where I_0 is the intensity of the flux of the scattered particles per unit solid angle when an unpolarized beam is scattered by an unpolarized target, $\mathbf{P}_B$ and $\mathbf{P}_T$ are respectively the polarizations of the beam and of the target, $\mathbf{P}_{pp}$ is the polarization in the elastic pp scattering, and $d\omega$ is the solid angle of the detector.

In the case considered here, four combinations of target and beam polarizations are possible. Accordingly, four quantities can be measured in the experiment, namely the intensities $I_{++}, I_{+-}, I_{-+}, I_{--}$, referred to the monitor, where the first and second signs are those of the target and beam polarizations. The four measured quantities make it possible to determine from the experiment the following asymmetries:

$$\begin{aligned}
\varepsilon_{+-,+-}&=(I_{++}+I_{--}-I_{+-}-I_{-+})(I_{++}+I_{--}+I_{+-}+I_{-+})^{-1},\\
\varepsilon_{+-,-}&=(I_{+-}-I_{--})(I_{+-}+I_{--})^{-1},\\
\varepsilon_{+-,+}&=(I_{++}-I_{-+})(I_{++}+I_{-+})^{-1},\\
\varepsilon_{+,+-}&=(I_{++}-I_{+-})(I_{++}+I_{+-})^{-1},\\
\varepsilon_{-,+-}&=(I_{--}-I_{-+})(I_{--}+I_{-+})^{-1}.
\end{aligned} \qquad (2)$$

The polarization correlation coefficient C_{nn} of interest to us is connected with the asymmetries ε in the following manner:

$$\begin{aligned}
C_{nn}^{+-,+-}&=\frac{\varepsilon_{+-,+-}[1-0.5(\beta P_B+\tau P_T)\mathbf{P}_{pp}\mathbf{n}]}{P_BP_T[(1-\beta/2)(1-\tau/2)-\varepsilon_{+-,+-}\beta\tau/4]},\\
C_{nn}^{+-,-}&=\frac{P_T(1-\tau/2)\mathbf{P}_{pp}\mathbf{n}+\varepsilon_{+-,-}[1-(P_B+P_T\tau/2)\mathbf{P}_{pp}\mathbf{n}]}{P_BP_T[1-(1-\varepsilon_{+-,-})\tau/2]},\\
C_{nn}^{+-,+}&=\frac{-P_T(1-\tau/2)\mathbf{P}_{pp}\mathbf{n}+\varepsilon_{+-,+}[1+(P_B(1-\beta)+P_T\tau/2)]\mathbf{P}_{pp}\mathbf{n}}{P_BP_T[(1-\beta)(1-\tau/2)+\varepsilon_{+-,+}\tau/2]},\\
C_{nn}^{+,+-}&=\frac{-P_B(1-\beta/2)\mathbf{P}_{pp}\mathbf{n}+\varepsilon_{+,+-}[1+(P_T(1-\tau)+P_B\beta/2)\mathbf{P}_{pp}\mathbf{n}]}{P_TP_B[(1-\beta/2)(1-\tau)+\varepsilon_{+,+-}(1-\tau)\beta/2]},\\
C_{nn}^{-,+-}&=\frac{P_B(1-\beta/2)\mathbf{P}_{pp}\mathbf{n}+\varepsilon_{-,+-}[1-(P_T+P_B\beta/2)\mathbf{P}_{pp}\mathbf{n}]}{P_TP_B[1-(1+\varepsilon_{-,+-})\beta/2]},
\end{aligned} \qquad (3)$$

where

$$\tau=1-P_T^+/P_T^-, \quad \beta=1-P_B^+/P_B^-, \quad P_B=P_B^-, \quad P_T=P_T^-,$$

$P_T^-(P_T^+)$ and $P_B^-(P_B^+)$ are the values of the polarization of the target and of the beam respectively at negative (positive) direction of these polarizations relative to the normal end to the plane of the left-hand scattering.

Naturally, the five values of C_{nn}^{pp} obtained in this manner are not independent, but the fact that they are equal within the limits of statistical errors means that there are no systematic errors.

To determine $I_{++}, I_{+-}, I_{-+}, I_{--}$ we measured in the experiment the number of particles registered by a given detector from the polarized target after subtracting the background due to the complex nuclei contained in the target. The background due to the complex nuclei was measured in an experiment with the hydrogenless equivalent of the PPT.

To determine the false asymmetry and to check on the accuracy of the measurement of the PPT polarization, we measured the asymmetry in the experiment twice, by scattering an unpolarized proton beam of the same energy by the PPT. The PPT polarization obtained in this manner agreed within the limits of experimental error (3–5%) with the PPT polarization measured by the NMR method. To reduce the experimental results obtained for the polarization in elastic pp scattering, we used the previously published data averaged in the course of the phase-shift analysis in the interval 590–635 MeV in[1].

RESULTS

The various types of asymmetry measured in four runs of scattering of a polarized beam by a polarized target are listed in Table I. The values of C_{nn}^{pp} obtained from the asymmetries of Table I are listed in Table II. The errors indicated in Table II include the errors in the measurement of the target polarization (4%) of the beam polarization (5%). It should be noted that from the results of runs 3 and 4 we determined all five types of asymmetry and the corresponding values of C_{nn}^{pp} (see formulas (2) and (3)). The mean values of C_{nn}^{pp} in this case coincides within three standard deviations. Consequently Tables I and II list only the most accurate values of ε and C_{nn}^{pp}.

We present below the values of the polarization in elastic pp scattering, obtained in a calibration experiment with an unpolarized beam:

ϑ (cms):	40°	67°	78°	90°
P_{vp}:	0.481±0.028	0.326±0.010	0.227±0.009	−0.003±0.006
P_{pp} [1]:	0.510±0.005	0.332±0.005	0.232±0.004	0

TABLE II.

Run number	Type of C_{nn}	Value of C_{nn}			
		$\vartheta=40°$	67°	78°	90°
1	$C_{nn}^{+-,-}$		0,65±0.06		0.54±0,06
2	$C_{nn}^{+-,-}$	0.59±0.13	0.58±0,05	0.63±0.06	0.56±0.05
3	$C_{nn}^{+-,+-}$	0.66±0.06	0.53±0.04	0.59±0.04	0.59±0.05
4	$C_{nn}^{+-,+-}$	0.55±0.06	0.57±0.04	0.52±0.04	0.58±0.05
Average		0.60±0.05	0.57±0.04	0.57±0.04	0.57±0.04

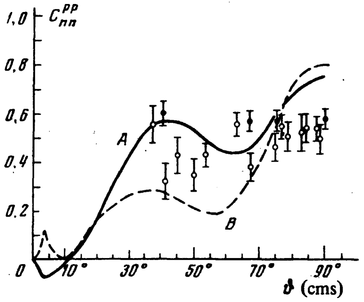

FIG. 2. Dependence of C_{nn} on the scattering angle (cms): ●—present work, $T_p = 610$ MeV, ○—from[3], $T_p = 575$ MeV. The solid and dashed curves are the $C_{nn}(\vartheta)$ predicted on the basis of the results of a phase-shift analysis for sets A and B, respectively.[1]

For comparison, the last line gives data on the polarization in elastic pp scattering, averaged in[1] over the interval 590–635 MeV, from the results of earlier papers.[2–10] It is seen that the measured values of the polarization in elastic pp scattering at 610 MeV agree well with the data of[1] averaged over the interval 590–635 MeV. The latter indicates that the results of the measurement of the polarization of the target of the NMR method agree within 3–4% with the target polarization obtained from the asymmetry in elastic pp scattering, measured with an unpolarized beam.

The obtained values of C_{nn} are compared in Fig. 2 with the results of the phase-shift analysis[1] and with the data obtained at 575 MeV.[3] It is seen from Fig. 2 that the dependence of C_{nn} on the scattering angle ϑ, obtained in this experiment, confirms quite satisfactorily the phase-shift set A and seems to exclude the set B. It is also seen that the polarization correlation coefficient C_{nn} depends little on the energy in the energy interval 575–610 MeV.

It should be noted, in conclusion, that a polarized proton target of the frozen type, despite the complicated construction, turns out to be quite convenient and reliable for accelerator experiments. The long relaxation time makes it possible to carry out measurements of the target polarization not more frequently than once than 10–20 hours of operation, thus relieving the experimenter of the need for continuously monitoring the target polarization, which is replaced by the much simpler monitoring of the temperature. The refrigerator of the target can maintain the working temperature of the sample at 0.04°K in a beam with a proton intensity $\sim 10^7$ cm^{-2} sec^{-1} in the presence of noticeable mechanical vibrations.

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