CORRELATION BETWEEN THE NORMAL POLARIZATION COMPONENTS IN pp *SCATTERING AT* 650 Mev. *I*

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In a program including a complete set of experiments for the determination of nucleon-nucleon scattering amplitudes, we measured the coefficient of correlation between the normal polarization components (the parameter C_{nn}) in elastic pp scattering at 650 Mev and 90° (c.m.s.). We obtained $C_{nn}(90°) = 0.93 \pm 0.20$. The moduli of the respective amplitudes contained in the elastic pp-scattering matrix were calculated on the basis of the obtained experimental values.

1. INTRODUCTION

IN one of our earlier papers[1] we formulated several possible sets of experiments, by which the amplitudes of nucleon-nucleon scattering can be determined by a simultaneous analysis of data on np and pp scattering. All these sets involve a determination of the correlation coefficient $C_{nn}(\vartheta)$ of the normal components of the polarization of nucleons in pp scattering. This coefficient is determined in terms of the average value of the operator $(\boldsymbol{\sigma}_1 \cdot \mathbf{n})(\boldsymbol{\sigma}_2 \cdot \mathbf{n})$, the value of which is

$$\langle(\sigma_1\mathbf{n})(\sigma_2\mathbf{n})\rangle = \mathrm{Sp}\, MM^+(\sigma_1\mathbf{n})(\sigma_2\mathbf{n})/\mathrm{Sp}\, MM^+, \quad (1)$$

and the quantity

$$I_0(\vartheta) = \tfrac{1}{4}\,\mathrm{Sp}\, MM^+, \quad (1a)$$

where M is the amplitude of elastic pp scattering; σ_i is the spin matrix of the i-th nucleon; $\mathbf{n} = [\mathbf{k}_i \times \mathbf{k}_f]/|[\mathbf{k}_i \times \mathbf{k}_f]|$ is a unit vector normal to the nucleon scattering plane; $I_0(\vartheta)$ is the scattering cross section of unpolarized nucleons by unpolarized nucleons through an angle ϑ in the c.m.s. of both nucleons.

Using for M the expression proposed by Wolfenstein[2]

$$M = BS + C(\sigma_1 + \sigma_2)\mathbf{n} + N(\sigma_1\mathbf{n})(\sigma_2\mathbf{n})T + \tfrac{1}{2}G[(\sigma_1\mathbf{m})(\sigma_2\mathbf{m}) + (\sigma_1\mathbf{l})(\sigma_2\mathbf{l})]T + \tfrac{1}{2}H[(\sigma_1\mathbf{m})(\sigma_2\mathbf{m}) - (\sigma_1\mathbf{l})(\sigma_2\mathbf{l})]T, \quad (2)$$

we write the pp-scattering cross section in the form

$$I(\vartheta) = \tfrac{1}{4}|B|^2 + 2|C|^2 + \tfrac{1}{4}|G-N|^2 + \tfrac{1}{2}|N|^2 + \tfrac{1}{2}|H|^2. \quad (3)$$

The coefficient of spin correlation $C_{nn}(\vartheta)$ is defined here as

$$I_0(\vartheta)C_{nn}(\vartheta) = -\tfrac{1}{4}|B|^2 + 2|C|^2 - \tfrac{1}{4}|G-N|^2 + \tfrac{1}{2}|N|^2 + \tfrac{1}{2}|H|^2. \quad (3a)$$

If we use for the scattering amplitude another frequently employed expression[1,3,4]

$$M = \alpha + \beta(\sigma_1 + \sigma_2)\mathbf{n} + \gamma(\sigma_1\mathbf{n})(\sigma_2\mathbf{n}) + \delta(\sigma_1\mathbf{l})(\sigma_2\mathbf{l}) + \varepsilon(\sigma_1\mathbf{m})(\sigma_2\mathbf{m}), \quad (4)$$

then the scattering cross section $I_0(\vartheta)$ and the coefficient of spin correlation $C_{nn}(\vartheta)$ assume the form

$$I_0(\vartheta) = \tfrac{1}{2}(|a|^2 + |b|^2 + |c|^2 + |d|^2 + |e|^2), \quad (5)$$

$$I_0(\vartheta)C_{nn}(\vartheta) = \tfrac{1}{2}(|a|^2 - |b|^2 - |c|^2 + |d|^2 + |e|^2); \quad (5a)$$

$$a = \alpha + \gamma, \quad b = \alpha - \gamma, \quad c = \delta + \varepsilon, \quad d = \delta - \varepsilon, \quad e = 2\beta. \quad (6)$$

The main principles of the determination of the coefficient $C_{nn}(\vartheta)$ were considered by Smorodinskii et al.[4,5] In the present communication, which is the first part of a paper on the determination of the coefficients $C_{nn}(\vartheta)$ for pp scattering at 650 Mev, we describe the research procedure and report the results of the measurement of C_{nn} at 90° (c.m.s.).[6]

For this angle, expressions (3), (5) and (3a), (5a) are made simpler by the symmetry of the coefficients of the scattering amplitude:

$$I_0(90°) = \tfrac{1}{4}|B|^2 + 2|C|^2 + \tfrac{1}{2}|H|^2 = \tfrac{1}{2}(2|b|^2 + |d|^2 + |e|^2), \quad (7)$$

$$I_0(90^\circ)\, C_{nn}(90^\circ) = -\tfrac{1}{4}|B|^2 + 2|C|^2 + \tfrac{1}{2}|H|^2 = \tfrac{1}{2}(-2|b|^2 + |d|^2 + |e|^2). \qquad (8)$$

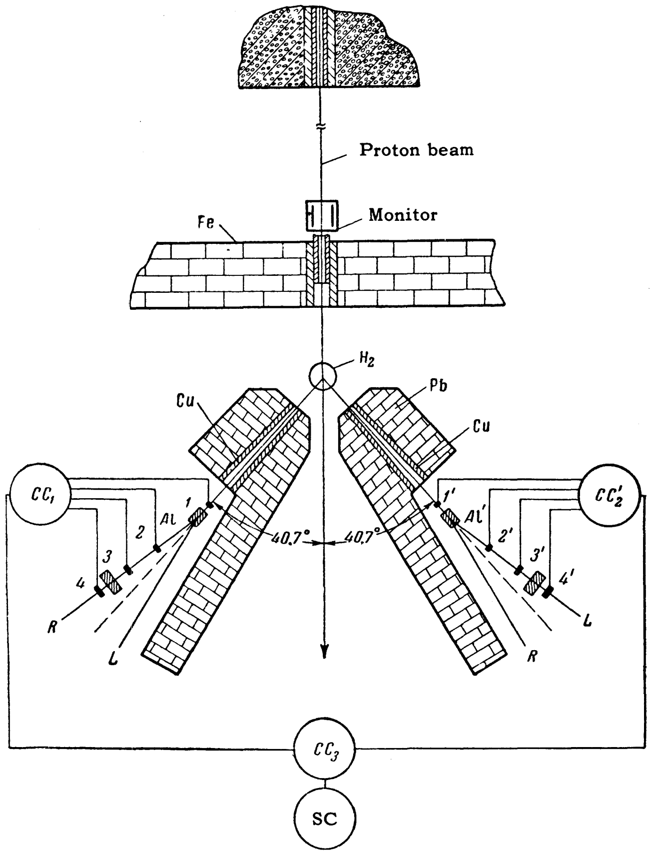
In addition, the value of $C_{nn}(90^\circ)$ is simply related to the contributions of the triplet I_{tr} and singlet I_s interactions to the scattering cross section $I_0(90^\circ)$:

$$I_{tr}(90^\circ)/I_0(90^\circ) = \tfrac{1}{2}[1 + C_{nn}(90^\circ)], \qquad (9)$$

$$I_s(90^\circ)/I_0(90^\circ) = \tfrac{1}{2}[1 - C_{nn}(90^\circ)]. \qquad (10)$$

2. EXPERIMENTAL LAYOUT

The experimental determination of the spin-correlation coefficients is based on the measurement of the asymmetry produced when the two protons from elastic pp scattering are simultaneously scattered on the polarization-analyzer targets. Our experimental layout is shown in the figure. An unpolarized proton beam, extracted from the synchrocyclotron chamber of the Joint Institute for Nuclear Research and cleared by the stray field of the accelerator magnet, was shaped by quadrupole lenses and then, after passing through steel collimators 20 mm in diameter in the main shielding wall and



Layout of apparatus in experiments for the measurements of the parameter C_{nn} (90°).

in the local shielding of the layout, struck a liquid-hydrogen target. The proton energy at the center of the liquid-hydrogen target was 650 ± 12 Mev.

The density of the proton current incident on the liquid-hydrogen target was monitored with an ionization chamber filled with helium at a pressure of 0.4 atm, and did not exceed $(3.3 \pm 0.3) \times 10^8$ cm^{-2} in this experiment. A check was made also in the experiments on the homogeneity of the density distribution of the proton current incident on the target.

The two protons involved in each event of elastic scattering by 90° in the c.m.s. were detected by conjugated scintillation counters 1 and 1′ with $20 \times 60 \times 10$ mm plastic scintillators. The angular resolutions of the first scattering in the horizontal projection were ± 1.5°, and the resolution in the azimuthal angle was ± 3.6°.

The scattered protons and the recoil protons passed through collimating slots in the supplementary shielding of the layout and struck aluminum polarization-analyzer targets (20 g/cm^2). The counter system 2, 3, 4 and 2′, 3′, 4′, with scintillator dimensions $23 \times 50 \times 10$, $40 \times 90 \times 10$, and $50 \times 110 \times 10$ mm respectively, detected the protons scattered in the analyzers by an angle 11 ± 2.5° (l.s.).

Pulses from the photomultiplier anodes were fed first to shaping networks, where they were limited in amplitude and shaped in duration, and then to the inputs of two four-channel coincidence circuits, CC_1 and CC_2', with resolution time $\tau = 7.5 \times 10^{-9}$ sec. The pulses produced at the outputs of these circuits were additionally shaped in amplitude and duration, and then analyzed for coincidence with each other within the limits of a resolving time of 7.5×10^{-8} sec.

Thus, the two-channel coincidence circuit CC_3, connected with scaler circuit SC, picked out the "triple" scattering cases, i.e., cases when the scattered particle and the recoil particle were simultaneously scattered in the analyzing targets through angles specified by the geometry of the experiment.

In 90° (c.m.s.) elastic pp scattering the polarization of the two proton beams (scattered and recoil protons) incident on the analyzer targets should, as is well known, be equal to zero. The polarization of this beam was monitored simultaneously with the main measurements and it was found that the polarization of the proton beams (due, for example, to imperfect alignment of the beams and counters), if it exists at all, does not exceed 0.003 ± 0.002 in absolute magnitude.

3. CALIBRATION EXPERIMENT

A calibration experiment was carried out to determine the analyzing ability of the second-scattering targets. In this experiment the protons were slowed down to 385 Mev by polyethylene absorbers placed near the accelerator chamber, while counters 1 and 1′, used to determine the first-scattering angle, where so placed as to separate the protons scattered in the c.m.s. through an angle $\vartheta = 41°$ ($\theta_{l.s.} = 19°$). The protons incident on the second scatterers had then the same energy, 325 Mev, as in the correlation experiments, and their polarization under these conditions was $P = 0.39 \pm 0.03$.*

It was found that when a copper absorber is placed between the counters (together with an aluminum scatterer), so that the proton registration threshold is set at 260 Mev, the asymmetries E_1 and E_2 in the scattering of the protons by the analyzer targets are given by $E_1 = 0.200 \pm 0.015$ and $E_2 = 0.210 \pm 0.016$. This corresponds to second-scattering analyzing abilities

$$P_1 = 0.51 \pm 0.056, \qquad P_2 = 0.54 \pm 0.06. \tag{11}$$

4. CORRELATION ASYMMETRY AND THE COEFFICIENT $C_{nn}(90°)$

The coefficient $C_{nn}(90°)$ is given by the expression $C_{nn}(90°) = e/P_1P_2$, where e is the correlation asymmetry. The experimental value of the correlation asymmetry e′ was determined from the relation

$$e' = \frac{(N_{LL} + N_{RR}) - (N_{RL} + N_{LR})}{N_{LL} + N_{RR} + N_{RL} + N_{LR}}, \tag{12}$$

where N_{LL}, N_{RR}, N_{LR}, and N_{RL} are the counting rates of the double coincidence circuit CC_3 in the positions LL, RR, LR, and RL, respectively (see the figure). The values of N_{LL}, N_{RR}, N_{LR}, and N_{RL} were determined by subtracting the background of the layout from the total counting rates of the CC_3 circuit with both analyzing targets in place.

The background of the layout is:

$$N_b = N^{+-} + N^{-+} - N^{--} + 0.05\,N^{++}. \tag{13}$$

Here N is the counting rate of the coincidence circuit CC_3, and the index + or − denotes the respective presence or absence of the first and second analyzing targets. The measurements have shown that $N^{--} \ll N^{++}$ and $N^{+-} = N^{-+}$. The correction term $0.05\,N^{++}$ is due to the 5-percent background of random coincidences in coincidence circuit CC_3. The total background N_b amounts to approximately 25 percent of N^{++}.

As a result of several measurement runs and subsequent averaging, the correlation asymmetry was found to be $e' = 0.267 \pm 0.037$. To determine the true correlation asymmetry e it is necessary to introduce into the obtained value e′ a correction for false correlation e_f, due to the geometry of the layout. Calculations have shown that $e_f = 0.01 \pm 0.04$.

From the resultant values

$$P_1 = 0.51 \pm 0.056, \qquad P_2 = 0.54 \pm 0.060, \qquad e = e' - e_f = 0.257 \pm 0.37, \tag{14}$$

it follows that

$$C_{nn}(90°) = 0.93 \pm 0.20. \tag{15}$$

5. DISCUSSION OF RESULTS

1. By using relations (9) and (10), as well as the average value of the spin-correlation coefficient (15), we find that at 650 Mev the triplet interaction produces a contribution of 96 percent to the cross section for elastic scattering $I_0(90°)$. The contribution of the singlet interaction is merely 4 percent.

A comparison of the value of the parameter $C_{nn}(90°) = 0.93 \pm 0.20$, obtained at 650 Mev proton energy, with the known values of this parameter for 310 Mev[8] [$C_{nn}(90°) = 0.84^{+0.10}_{-0.22}$] and 382 Mev[9] [$C_{nn}(90°) = 0.416 \pm 0.084$] points to a possible non-monotonicity in the variation of the ratio of the contributions of the triplet and singlet interactions to elastic pp scattering in the energy interval 300 — 650 Mev.

2. If we take into consideration the connection existing between the experimentally measured values of the parameters $C_{nn}(\vartheta)$ and $D_{nn}(\vartheta)$ (the depolarization coefficient) and the absolute values of the quantities B, C, H, G, N or a, b, c, d, and e, then the experimental data presently available on pp scattering at 650 Mev are sufficient to determine the moduli of the amplitudes contained in the matrix of elastic pp scattering by an angle $\vartheta = 90°$. The calculated moduli of the coefficients of the scattering matrix (2) and moduli of the quantities (6) are

$$\frac{1}{4}\frac{|B(90°)|^2}{I_0(90°)} = \frac{1}{2}\frac{|b(90°)|^2}{I_0(90°)} = \frac{1 - C_{nn}(90°)}{2} = 0.035 \pm 0.1, \qquad |b(90°)|^2 = |c(90°)|^2, \tag{16}$$

*This value of the polarization was obtained by averaging the data contained in the review by Hess[7] for polarization at 314 Mev (P = 0.38 ± 0.02), 315 Mev (P = 0.38 ± 0.02), and 415 Mev (P = 0.41 ± 0.03).

$$\frac{2\,|C(90°)|^2}{I_0(90°)} = \frac{1}{2}\frac{|e(90°)|^2}{I_0(90°)} = \frac{1}{4}(1 + C_{nn}(90°) + 2D_{nn}(90°)) = 0.95 \pm 0.1, \tag{17}$$

$$\frac{1}{2}\frac{|H(90°)|^2}{I_0(90°)} = \frac{1}{2}\frac{|d(90°)|^2}{I_0(90°)} = \frac{1}{4}(1 + C_{nn}(90°) - 2D_{nn}(90°)) = 0.02 \pm 0.1 \tag{18}$$

$$N(90°) = G(90°) = a(90°) = 0. \tag{19}$$

We used here the value of the parameter $D_{nn}(90°) = 0.93 \pm 0.17$, obtained in [10] at practically the same proton energy.

3. Knowledge of the values of the moduli of the amplitudes B, C, and H permits, in principle, an estimate of the Wolfenstein parameters R(90°) and A(90°) at 650 Mev. It is necessary to use for this purpose, for example, the analytic expressions for the relative phase shifts of these amplitudes. The estimates carried out have shown that when $C_{nn}(90°) = 0.93$ the parameters R(90°) and A(90°) differ little in magnitude and do not exceed 0.25.

[1] Golovin, Dzhelepov, Nadezhdin, and Satarov, JETP **36**, 433 (1959), Soviet Phys. JETP **9**, 302 (1959).

[2] L. Wolfenstein, Phys. Rev. **96**, 1654 (1954).

[3] R. Oehme, Phys. Rev. **98**, 147 (955).

[4] Puzikov, Ryndin, and Smorodinskii, JETP **32**, 592 (1957), Soviet Phys. JETP **5**, 489 (1957).

[5] V. Vladimirskii and Ya. Smorodinskii, DAN SSSR **104**, 713 (1955).

[6] V. P. Dzhelepov, Proc. 1960 Ann. Intern. Conf. on High-Energy Physics at Rochester, Publ. Univ. Rochester, 1961, p. 115.

[7] H. Hess, Revs. Modern Phys. **30**, 368 (1958).

[8] Vasilevsky, Visnyakov, Iliesku, and Tyapkin, op. cit. [6] p. 200.

[9] Ashmore, Diddens, Huxtable, and Skarvag, Proc. Phys. Soc. **72**, 289 (1958).

[10] Kumekin, Meshcheryakov, Nurushev, and Stoletov, JETP **35**, 1398 (1958), Soviet Phys. JETP **8**, 977 (1959).

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