MEASUREMENT OF THE SPIN CORRELATION COEFFICIENT IN ELASTIC 315-MeV PROTON-PROTON SCATTERING

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Submitted to JETP editor April 2, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 474-479 (September, 1963)

The experimental procedure is described and the result of the measurement of the spin correlation coefficient ($C_{nn} = 0.76 \pm 0.15$) is presented for elastic 315-MeV proton-proton scatscattering at 90° (c.m.).

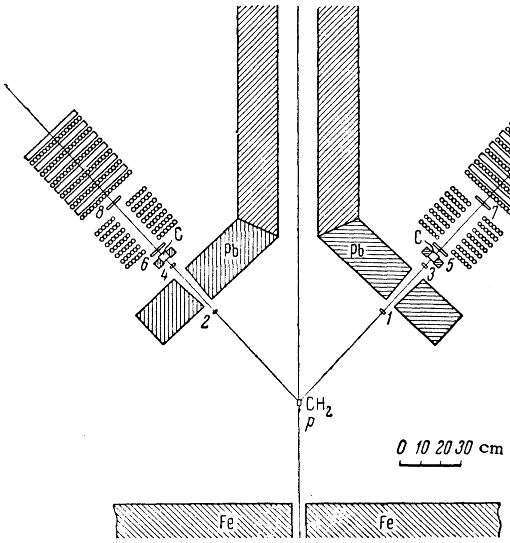
THE phase-shift analysis of data on elastic interactions of 310-MeV protons originally yielded five different solutions.[1] Further development and improvement of the analysis reduced the number of possible phase-shift sets to two.[2] The modified analysis further took into account a contribution from high orbital momentum states on the basis of the single-meson approximation developed in [3,4]. A unique determination of the phase-shift sets required more precise measurements of previously investigated quantities as well as measurements of additional quantities not involved in the originally selected full set of data on elastic proton scattering. The latter factors include the polarization correlation of scattered protons and recoil protons. The possibility of obtaining information regarding interactions of nucleons in different spin states by investigating spin correlation coefficients in experiments with unpolarized targets was pointed out in [5]. Difficulties in determining the polarization tensor components in these experiments were associated with the necessity of registering rare triple nuclear reactions in the main target and in two analyzing targets. The spin correlation coefficient was first measured by a Liverpool group[6] for elastic 382-MeV p-p scattering at c.m. 90°. The correlation $C_{nn} = 0.416 \pm 0.084$ was obtained between the spin components normal to the scattering plane. However, the difficulty of extrapolating this value of $C_{nn}(90°)$ to 310 MeV prevented the reaching of any definite conclusion from a comparison of this result with the values 0.38 and 0.61 corresponding to the first and second sets of phase shifts.

The measured values of $C_{nn}(90°)$ obtained in Liverpool at 320 MeV and in Dubna at 315 MeV favored the second phase-shift set.[7-9] The Liverpool group obtained $C_{nn}(90°) = 0.75 \pm 0.11$. Measurements by our group utilizing provisional data from a calibration experiment to determine the polarizing power of the graphite analyzers yielded $C_{nn}(90°) = 0.7 \pm 0.3$. Following the conclusion of the calibration experiment we obtained $0.84^{+0.10}_{-0.22}$.[10]

The large experimental value of $C_{nn}(90°)$ was in poor agreement with the theoretical prediction based on the first set of phase shifts. However, the first set was favored by a phase-shift analysis with smaller values of the orbital momenta considered in the one-meson approximation.[11] Thus when 7 phase shifts are considered instead of the previous 14 only the first set gives a satisfactory description of the experimental results. When 9 phase shifts are considered, better agreement is obtained with the first set and satisfactory agreement with the second set. At the same time, the calculated values of $C_{nn}(90°)$ obtained with the redetermined values of 9 phase shifts were approximately 0.41 for both the first and second sets.

In order to check the reliability of the previously obtained large experimental value of $C_{nn}(90°)$ we continued to collect statistics regarding the scattering of both protons in carbon analyzers. The correlation asymmetry was measured using apparatus consisting of scintillation counters and a hodoscopic system of pulsed gas-filled counters.

A 660-MeV proton beam extracted from the synchrocyclotron of the Joint Institute for Nuclear Research was slowed down to 315 MeV. After testing several means of slowing the proton beam we selected the most efficient method, which yielded a total intensity of about 10^7 protons/sec in a 315-MeV beam. The carbon absorber was placed immediately outside the accelerator vacuum chamber. After traversing the absorber the beam was deflected 16° by an analyzing magnet, which guided it into the steel collimator 100 mm thick located inside a 4-meter concrete wall. At the exit of the



collimator quadrupole lenses with an 120-mm aperture were set up in the room. The beam then traversed collimators having diameters of 40 and 50 mm in an auxiliary shield before striking a polyethylene target 20 mm wide and 30 mm in length and height. The arrangement of the registering apparatus is shown schematically in the accompanying figure. Elastic p-p scattering events were selected by means of two coupled telescopes consisting of scintillation counters 1—4 connected for coincidence. All four scintillators were of the same size (90 mm high, 30 mm wide and 7 mm thick) and were made of a luminescent plastic material. The telescopes were placed symmetrically at 42.7° from the proton beam. The angular resolution of first scattering was ± 0.93°.

With normal accelerator operation the coincidence count was about 2000/minute. The coupled telescopes reliably discriminated elastic scatterings of protons on hydrogen nuclei. The coincidence count was reduced by a factor of 25 when an equivalent carbon target replaced the polyethylene target.

The protons selected by the telescopes passed through carbon analyzers 6.4 g/cm^2 thick, which were followed by counters 5—8 with the plastic scintillators. Counters 5 and 6 were 100 mm high, 100 mm wide, and 10 mm thick; counters 7 and 8 were 200 m high, 100 m wide, and 10 mm thick. Counters 5 and 6 were connected for coincidence with the telescope counters, while 7 and 8 were connected for anticoincidence. The adjusted centers of the scintillators of counters 1, 3, 5, and 7 and of 2, 4, 6, and 8 lay with ± 0.5-mm accuracy on threads stretched from the center of the first target. Protons moving along a telescope axis and scattered in an analyzer at an angle greater than 7.75° in the horizontal plane did not pass through the anticoincidence counters.

The system of scintillation counters thus distinguished the rare events in which both protons interacted with carbon nuclei in the analyzers. When only one anticoincidence counter was included the count was 7% of the 1 + 2 + 3 + 4 + 5 + 6 coincidence count. When both anticoincidence counters were included the count was reduced to 0.5% of the coincidence count.

A much greater reduction of the count resulted when the anticoincidence counters were included while the carbon analyzers were absent from the telescopes. With one anticoincidence counter the count was 2—3% and with both counters it was reduced to 0.05—0.1% of the 1 + 2 + 3 + 4 + 5 + 6 coincidence count. The small residual count, which is accounted for (to a considerable extent) by interactions between protons and nuclei of the scintillators of counters 5 and 6, indicates the smallness of the background of accidental 1 + 2 + 3 + 4 + 5 + 6 coincidences.

For the purpose of registering the proton scattering direction the analyzers included two hodoscopes of pulsed gas-filled counters.[12] Each hodoscope was divided into two parts. In the first part, located between the analyzer and the anticoincidence counter, we used only vertically positioned MS-6 counters with 22-mm tube diameter and 190-mm cathode length. The second part of the hodoscope which followed the anticoincidence counter, consisted of six rows of the same kind of counters positioned vertically and six horizontal rows of counters having 32-mm tube diameter and 290-mm cathode length. Whenever the system of scintillation counters registered an 1 + 2 + 3 + 4 + 5 + 6 − 7 − 8 event the gas-filled counters received a high voltage pulse ~ 2 kV and ~ 1 μsec length.

Neon lamps were placed in exact correspondence with the gas-filled counters on a cinematographically photographed panel. The panel was photographed whenever the scintillation counters registered 1 + 2 + 3 + 4 + 5 + 6 − 7 − 8 events. An average of 14 frames out of 100 revealed horizontal track projections of both scattered protons. Only these frames provided data that could be used in determining the relative probabilities of right-right (RR), left-left (LL), right-left (RL), and left-right (LR) proton scattering. The only tracks considered in the scanning of the photographs were those indicated by three or more flashing neon lamps and departing from the carbon target without crossing through the anticoincidence counters. The number of unlit lamps ahead of or between the lit lamps had to be smaller than the number of the latter. A typical case in which both protons were scattered is given in [12].

The resolving time of the hodoscopic system was about 2×10^{-6} sec. Therefore the selected frames could include events where only one of the hodoscopes registered the track of a scattered proton that was registered by the control system of scintillation counters, while the second hodoscope observed the track of a random particle, satisfying the scattering conditions, whose transit coincided within the limits of the resolving time with the instant of the selcted $1+2+3+4+5+6-7-8$ event. One advantage of the hodoscopic systems used in the present work is that no additional time was required for special measurements in order to determine the probability of background tracks.

We recorded 10,869 scatterings of protons traversing three or more counter trays at angles from 6° to 25°. These events were distributed among the correlation combinations as follows:

$$N_{RR} = 2815, \quad N_{LL} = 3074, \quad N_{RL} = 2460, \quad N_{LR} = 2520.$$

The mean background was $N_b = 110$ events.[1)] Hence the effective correlation asymmetry for proton scattering events in the given intervals of angles and ranges was

$$e' = \frac{N_{RR} + N_{LL} - N_{RL} - N_{LR}}{N_{RR} + N_{LL} + N_{RL} + N_{LR} - N_{\Phi}} = 0.0844 \pm 0.0096.$$

After introducing a correction for spurious correlation due to the geometry of the scattering selection system, $\Delta e_{sp} = -0.015 \pm 0.005$, we obtain the correlation

$$e = e' + \Delta e_{sp} = 0.0694 \pm 0.0110.$$

A previously performed calibration showed that the mean polarizing power of the analyzers for scattered protons registered in the given intervals of angles and ranges is

$$p_1 = p_2 = 0.318 \pm 0.022.$$

Hence the spin correlation coefficient is

$$C_{nn} = e/p_1p_2 = 0.69 \pm 0.15.$$

In the calibration run performed on a 160-MeV proton beam polarized in scattering on carbon at 20°, we obtained data on the polarizing power of the carbon analyzers for the different proton scattering angles and ranges registered by the hodoscopic counters. The derived dependence of the polarizing power on the scattering angle and especially the sharp dependence on the numbers of counter trays traversed by the scattered protons indicate the inadvisability of determining C_{nn} from the mean values of the correlation asymmetry and polarizing power of the analyzers, as determined from the complete treatment of the data for broad intervals of proton angles and ranges. Thus for the scattering angles from 19° to 21° the polarizing power was 0.94 ± 0.02 for protons traversing eight or more counter trays, while it was 0.43 ± 0.04 for protons traversing from three to seven trays. Similar variations of the polarizing power occur for other angular intervals when the results of the calibration run are divided into two groups according to the proton ranges.

We have therefore treated the data separately, with respect to measurement of the correlation asymmetry $e_{i,j}$, in each of four different angular intervals in the region from 11° to 25° and for two groups of scattered proton ranges. These regions included a total of 2183 proton scatterings in both hodoscopes. For each value of $e_{i,j}$ we obtained $(C_{nn})_{i,j} = e_{i,j}/p_ip_j$ using the appropriate values of the polarizing powers determined in the calibration run. By averaging these values of $(C_{nn})_{i,j}$ with appropriate weights we obtained the mean spin correlation coefficient $C_{nn}(90°) = 0.76 \pm 0.15$. Therefore the differential treatment, despite a considerably smaller amount of treated data, leads to the same reliability of C_{nn} as the total treatment of all the data. The differential treatment taking into account only scatterings at angles greater than 10° eliminated the spurious asymmetry resulting from the geometry of the scattering-event selection system.

Thus our continued measurements, like the previous measurements, yield a large value of $C_{nn}(90°)$, in good agreement with the experimental results obtained by the Liverpool group.[8,13] The discrepancy between the experimental values

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1)The background comprised events in which one of the hodoscopes registered the track of a scattered proton that was registered by the scintillation counters, while the second hodoscope registered the track of a random particle satisfying the scattering conditions and passing through during the hodoscope resolving time. The probability of these events was calculated by computing the number of cases in which a hodoscope recorded both the track of a scattered proton and the track of a random particle traversing an anticoincidence scintillation counter, and by using the experimental ratio of scattered particles to the total number of particles traversing the carbon analyzer. The background was also determined independently from the number of observed events with two scattered particle tracks in one hodoscope, taking into account the data obtained, although at reduced intensity, regarding the production of these particles in nuclear disintegrations. Through neglect of the latter factor our value of the background in [9] was too high.

of $C_{nn}(90°)$ and the result calculated in [11] for the first and second sets of phase shifts can serve to indicate the inadequacy of taking 9 phase shifts into account in the analysis. It should also be remembered that a comparison between the experimental value of C_{nn} and the calculated values for different sets of phase shifts without considering the admissible deviations of the phase shifts does not permit any conclusion regarding agreement or disagreement with any particular set of phase shifts.

For example, MacGregor's recent analysis, [14] taking into account 14 phase shifts and the pion-nucleon interaction constant, showed that inclusion of the experimental value of $C_{nn}(90°)$ does not result in a disagreement with either the first or second set and requires only an insignificant change of the phase shifts. A phase analysis of n-p and p-p scatterings at 310 MeV taking into account the experimental $C_{nn}(90°)$, which was performed by Kazarinov and Silin, [15] also yields good agreement of the first and second sets with experiment. Consequently, for a unique determination of the set of phase shifts we require further refinement of the experimental values included in the analysis as well as a measurement of quantities that have not yet been investigated experimentally.

In conclusion we wish to thank B. M. Antonov and G. P. Zorin for experimental assistance, and N. N. Deryagina, O. A. Kropina, and L. S. Sidorova for assistance with the treatment of the experimental data.

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Translated by I. Emin
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