TRIPLE SCATTERING OF 660-Mev PROTONS

*I. MEASUREMENT OF THE DEPOLARIZATION PARAMETER D(90°)**

Iu. P. KUMEKIN, M. G. MESHCHERIAKOV, S. B. NURUSHEV, and G. D. STOLETOV

Joint Institute for Nuclear Research

Submitted to JETP editor July 15, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 1398-1401 (December, 1958)

Experiments on triple scattering of 660-Mev protons are described. The depolarization parameter D(90°) is found to be equal to 0.93 ± 0.17. This result indicates that p-p scattering through 90° is mainly due to the $C(\sigma_1 + \sigma_2)\cdot\mathbf{n}$ term in the scattering matrix.

1. INTRODUCTION

THE parameter D, introduced by Wolfenstein,[1] serves as a measure of the change in the normal component of the polarization vector in the second scattering. It follows from his formulas that for p-p scattering the depolarization parameter is determined by the expression

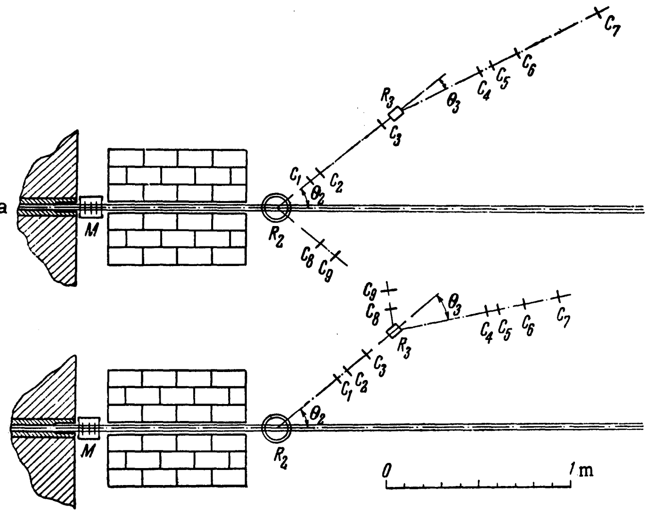
$$\sigma_0(1-D) = {}^1/_4\,|G-N-B|^2 + |H|^2,$$

where $\sigma_0 = \frac{1}{4}|B|^2 + 2|C|^2 + \frac{1}{4}|G-N|^2 + \frac{1}{2}|N|^2 + \frac{1}{2}|H|^2$ is the cross section for the scattering of an unpolarized proton beam by hydrogen, and B, C, G, H and N are five complex amplitudes of the p-p scattering matrix in the same notation as used in reference 1. The amplitudes B, C, G, H, and N are functions of the scattering angle and energy. The measurement of the parameter D is of considerable interest from the point of view of obtaining full information about p-p scattering, in particular if the measurement is performed at angles smaller and larger than 90° in the center of mass sytem (c.m.s.) where singlet-triplet interference might appear.

In this communication we report the results of a measurement of the depolarization parameter in p-p scattering at 90° in c.m.s. at 640 Mev. The experiment was performed on the six-meter synchrocyclotron of the Joint Institute for Nuclear Research.

2. EXPERIMENTAL PROCEDURE

660-Mev protons underwent first scattering inside the synchrocyclotron chamber from a beryllium target-polarizer 4 cm thick. A proton beam with polarization[2] $P_1 = 0.58 \pm 0.03$ and energy 640 ± 12 Mev was obtained, predominantly by diffraction scattering to the left at an angle of 9°. The flux density of the beam in the experimental area, after passage through a collimator 3 cm in diameter, was 7×10^5 protons/cm^{2}sec. The location of the second and third scatterers and the detection apparatus in the plane of the first scattering (which produces the polarized beam) are shown in the figure.



Schematic diagram of the location of the scatterers and detection apparatus in the scattering plane. M – monitor; R_2 – second target (vessel with liquid hydrogen); R_3 – third target: a – 5 × 8 × 6 cm graphite block, b – polyethylene block of the same dimensions; C_1 through C_9 – scintillation counters.

The second scattering took place in a glass vessel 12 cm in diameter filled with liquid hydrogen. The average energy of the protons was 635 Mev in the center of the second target. Three counters C_1, C_2 and C_3 selected the beam of twice-scattered protons. The profile of this beam was, for all practical purposes, symmetric with respect to the axis of the telescope $C_1C_2C_3$. In the second target, scattering of protons by protons took place

*Reported on May 22, 1958 at the IV Session of the Scientific Council of the Joint Institute for Nuclear Research.

at an angle $\theta_2 = 41 \pm 2.5°$ ($90 \pm 5°$ in the c.m.s.). The energy of the twice-scattered protons was 315 Mev with a spread of ±40 Mev.

The normal component of the polarization vector of doubly scattered protons was determined in two ways. In one method (Fig. 1a) the asymmetry ϵ_{3n} after a third scattering, through an angle $\theta_3 = 12°$, in a carbon target-analyzer was measured with the help of counters C_4, C_5, C_6 and C_7. The use of carbon as analyzer has definite advantages at large second scattering angles, when formation of π mesons in the third target is either negligible or absent altogether. The contribution from π mesons and secondary protons from the reactions $pp \rightarrow pn\pi^+$ and $pp \rightarrow pp\pi^0$ to the count of the protons elastically scattered from the second target was substantially reduced by detecting both elastically scattered protons with the conjugate telescopes $C_1C_2C_3$ and C_8C_9 whose opening angle corresponded to the kinematics of elastic p-p collisions. The counters were connected in groups of three to standard triple coincidence circuits ($\tau \approx 2 \times 10^{-8}$ sec), whose signals were in turn in coincidence. The plastic scintillators of counters C_1 through C_9 measured, in the horizontal and vertical directions respectively, 6.5 × 6.5, 6 × 7, 6 × 7, 6 × 6, 6 × 6.5, 6.5 × 7, 6.5 × 6.5, 7.5 × 12, and 8.5 × 13 cm and were 6 mm thick. The background of accidental coincidences did not exceed 3% of the hydrogen effect.

The second method (Fig. 1b) for the determination of the normal component of the proton polarization vector after the second scattering consisted of measuring the asymmetry ϵ_{3n} at an angle $\theta_3 = 30°$ after p-p scattering in the third target made of polyethylene. The scattering of 315-Mev protons by protons in the third target was differentiated from inelastic processes by registering both the scattered and recoil protons with the conjugate telescopes $C_4C_5C_6C_7$ and C_8C_9 placed first symmetrically to the right and then to the left of the beam which passed through the telescope $C_1C_2C_3$. The coincidence signals from the conjugate telescopes were picked up in coincidence with the signal from the telescope $C_1C_2C_3$. The background from accidental nine-fold coincidences with the same scintillators did not exceed 1% of the hydrogen effect. This method for determining the normal component of the polarization vector of doubly-scattered protons can be used when the second scattering is through amall angles and it becomes impossible to distinguish elastic p-p scatterings by means of conjugate telescopes.

The value of the depolarization parameter, when the second scattering is through 90° in the c.m.s., is given by

$$D(90°) = \varepsilon_{3n} / \varepsilon_3,$$

where ϵ_3 is the asymmetry obtained in scattering by the third target analyzer of a proton beam with polarization P_1 and energy equal to the energy of the protons in the doubly-scattered beam. The reduction in energy from 640 to 315 Mev of the once-scattered polarized beam was accomplished by a set of polyethylene and lead absorbers placed in the path of the protons before and after the purifying magnet in such a way that the angular spread of the slowed down protons was approximately the same as that of the proton beam which underwent a second scattering in the hydrogen target. Control experiments indicated that the slowing down of the protons did not depolarize the beam.

The measurement of the asymmetry ϵ_3 (calibration of the analyzer) was performed under the same geometrical conditions and with the same detection apparatus as the measurement of ϵ_{3n}. The counters C_1, C_2 and C_3 and the target analyzer were placed in the path of the slowed-down proton beam and the second hydrogen target was removed. In the calibration of the carbon analyzer, the asymmetry was determined by means of coincidences between the telescope $C_1C_2C_3$ (which selected the symmetric proton beam), and the telescope $C_4C_5C_6C_7$ (which registered the scattered protons). It should be emphasized that all measurements with the carbon analyzer were performed without a filter between the counters in the telescope $C_4C_5C_6C_7$, so that the observed asymmetries ϵ_3 and ϵ_{3n} were proportional to the polarization of the incident proton beam and to the analyzing power of the carbon as determined by the proton polarization from diffraction as well as from inelastic scattering. In the calibration of the polyethylene analyzer, p-p scattering was selected by means of conjugate telescopes in the same manner as in the measurement of the asymmetry ϵ_{3n} after p-p scattering in the third target.

In the processing of the experimental data, corrections were included for the background of accidental coincidences, for the effect of the empty liquid hydrogen vessel, and for the effect of the scintillator C_3, placed close to the third carbon target.

3. RESULTS

On the basis of data from nine separate series of measurements, we find that protons which are previously doubly scattered have, after scattering by the carbon target, an asymmetry

$$\varepsilon_{3n} = 0.200 \pm 0.032.$$

On the other hand, the calibration measurements of the asymmetry in the scattering by a carbon target of the primary polarized proton beam, whose energy was reduced to 315 Mev, gave the value

$$\varepsilon_3 = 0.216 \pm 0.012.$$

We indicate only statistical errors; they predominate over the systematic errors due to uncertainties in the estimates of various geometric factors. In a great majority of measurements values for ϵ_{3n} and ϵ_3 were obtained coinciding, within the error, with the average values of the corresponding quantities.

It follows from the values of the asymmetries ϵ_{3n} and ϵ_3 that

$$D(90^\circ) = 0.93 \pm 0.17.$$

The same result, but with smaller precision, was also obtained when the experiment was performed by the second method.

This value for D (90°) is noticeably larger than the values found at 310 (reference 3) and 415 Mev (reference 4), and is close to the upper limit of the -1 to $+1$ interval to which the values of D(90°) are confined. This fact indicates that the change in the normal component of the polarization vector in p-p scattering is small. In that case the amplitudes G and N of the scattering matrix vanish and the following relation results

$$D(90^\circ) = \frac{2|C|^2 - {}^1/_2|H|^2}{{}^1/_4|B|^2 + 2|C|^2 + {}^1/_2|H|^2}.$$

The proximity of D(90°) to +1 indicates that of all the terms entering into the p-p scattering matrix only the $C(\sigma_1 + \sigma_2)\cdot\mathbf{n}$ term is important for scattering through 90°. Judging from the average value of D(90°) the contribution to scattering through 90° of the $C(\sigma_1 + \sigma_2)\cdot\mathbf{n}$ term is not less than ~90%, the contribution of the tensor term $H[(\sigma_1\cdot\mathbf{k})(\sigma_2\cdot\mathbf{p}) - (\sigma_1\cdot\mathbf{p})(\sigma_2\cdot\mathbf{k})]$ may reach ~4%; thus the contribution of scattering in the singlet state is not more than ~7%. In Born approximation the $C(\sigma_1 + \sigma_2)\cdot\mathbf{n}$ term corresponds to a simple spin-orbit coupling.[5]

It should be noted that if D(90°) = 1 exactly, and consequently the scattering amplitudes are determined solely by the function C, all the polarization properties are determined uniquely once $\sigma_0(90^\circ)$ and D(90°) are measured. In that case all three tensors (correlation polarization P_{ik}, depolarization D_{ik}, and recoil polarization K_{ik}) are equal to each other and have only normal components:

$$P_{ik}(90^\circ) = D_{ik}(90^\circ) = K_{ik}(90^\circ) = n_i n_k$$

(n_i are the components of the normal $\mathbf{n}$)

The authors are obliged to Ia. A. Smorodinskii and R. M. Ryndin for useful discussions.

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

[2] Meshcheriakov, Nurushev and Stoletov, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 361 (1956), Soviet Phys. JETP **4**, 337 (1957).

[3] Ypsilantis, Wiegand, Tripp, Segrè, and Chamberlain, Phys. Rev. **98**, 840 (1955).

[4] Kane, Stallwood, Sutton, and Fox, Bull. Am. Phys. Soc. **1**, 9 (1956).

[5] L. Wolfenstein, Bull. Am. Phys. Soc. **1**, 36 (1956).

Translated by A. M. Bincer
299