Differential elastic-scattering cross section of 1-GeV protons by ^{4}He nuclei

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We measured the differential cross section for elastic scattering of 1-GeV protons by ^{4}He nuclei in the angle range $7° \leq \theta_{\rm cms} \leq 45.5°$. The relatively shallow depth of the diffraction maximum obtained in the experiment contradicts the calculations performed within the framework of the Glauber theory.

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The scattering of fast protons by nuclei is extensively used at present for the study of nuclear structure. This study was made possible by the fact that macroscopic approaches were developed for the interpretation of the experimental data. In particular, the good description of the differential cross sections of elastic proton-nuclear scattering is attained within the framework of the Glauber theory. [1] The first experimental confirmation of this theory was the agreement between the calculated p-^{4}He cross section[2] and the data obtained in Brookhaven at $E_p = 1.00$ GeV. [3] Subsequent studies[4–6] have shown that Glauber's theory describes equally well the scattering of protons by medium and heavy nuclei. Relatively recently, however, they measured in Saclay, at $E_p = 1.05$ GeV, the differential elastic p-^{4}He scattering cross section, in which the previously established diffraction minimum was practically nonexistent. [7] This result contradicts not only the earlier measurements, but also a large number of theoretical studies. [8] This raised a problem, on the solution of which depends, in many respects, the further development of scattering theory and the possibility of its use for the study of nuclear structure. Taking the importance of the problem into account, it seemed advantageous to organize a precision experiment on the elastic p-^{4}He scattering at an energy 1 GeV.

The measurements were made on a proton beam from the synchrocyclotron of the Leningrad Institute of Nuclear Physics with the aid of a magnetic spectrometer. [4] In this experiment we used an extended gas target (^{4}He at a pressure 15 atm at nitrogen temperature) and a multichannel system for the registration of the scattered protons in the focal plane of the spectrometer; this system consisted of a scintillation-counter telescope and multiple-wire proportional chambers. The energy resolution was ≈ 3.5 MeV at FWHM, and was sufficient for a reliable separation of the elastic-scattering peak from the background, which was negligibly small at small scattering angles and reached $\sim 20\%$ at large angles. The accuracy of the accurate normalization of the cross sections, which was effected by comparison with the known cross section for scattering by hydrogen, amounted to $\sim 15\%$. Particular attention was paid in

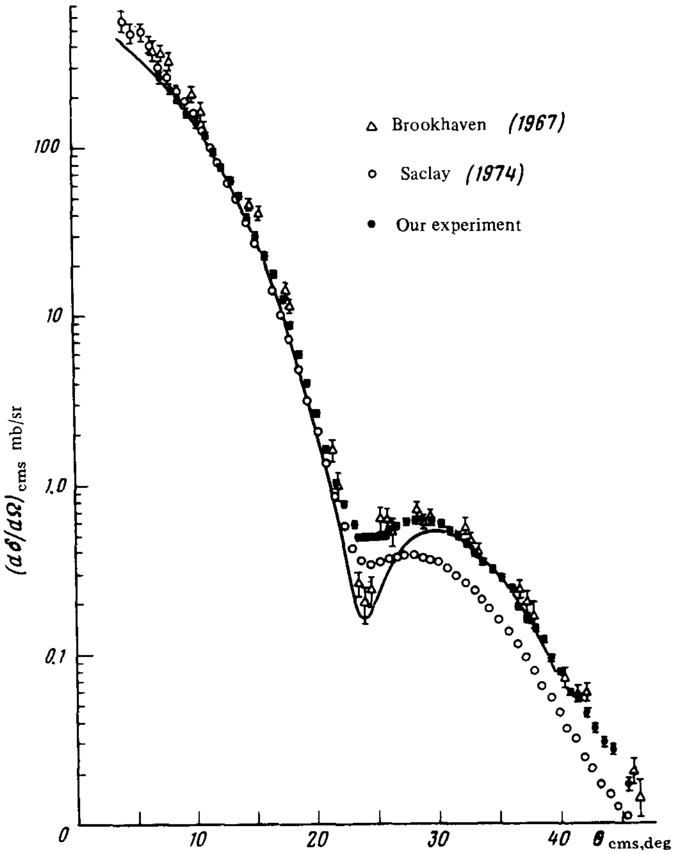

FIG. 1. Differential cross section for elastic scattering of protons by ^4He nuclei: Δ—Brookhaven data,[1] $E_p = 100$ GeV, ○—Saclay 1974 data,[7] $E_p = 1.05$ GeV, ●—our measurements, $E_p = 1.00$ GeV.

the experiment to the angular divergence of the primary proton beam, which measurements found to be $\langle(\delta\theta)^2\rangle^{1/2} \approx 0.24°$, and thus could not lead to a smearing of the diffraction minimum. Control measurements were also made, under analogous conditions, of the differential cross sections for elastic scattering by ^{12}C (the target was methane) and by ^{14}N. In both cases, deep diffraction minima were observed. In the case of helium (see Fig. 1), on the other hand, a cross section with a shallow minimum was obtained. By the same token, our measurements confirm qualitatively the Saclay data. At the same time, there are quantitative deviations from the Saclay data (see Fig. 1) both with respect to the minimum (~25% relative to the maximum and ~13% in our and Saclay data, respectively), and with respect to the value of the cross section at large angles.

The solid curve in Fig. 1 shows also the cross section calculated by the Glauber theory. The ^4He density was specified in the form of a three-parameter Fermi distribution.[9] The amplitude of the proton-nucleon scattering was approximated by the formula:

$$f_{p,n}(q) = (k\sigma_{p,n}/4\pi)(i + \epsilon_{p,n})\exp(-q^2\beta^2/2),$$

where $\sigma_p = 4.75$ F^2, $\sigma_n = 4.04$ F^2, $\epsilon_p = -0.1$, $\epsilon_n = -0.5$ and $\beta^2 = 0.21$ F^2. Account was taken of the mass-center correlations and of the interaction with the Coulomb field of the nucleus. It is seen that in the region of the diffraction minimum the theory predicts a cross section much smaller than the experimental one. At the present time there is no universally accepted explanation of this discrepancy.[10] For a better understanding of the mechanism of scattering by nuclei and to elucidate the role of the spin effect, it would be useful to carry out in the same angle range measurements of the polarization of the scattered protons.

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